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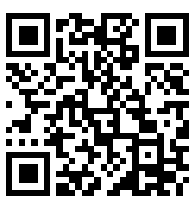

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# PROCEEDINGS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

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Junkersfeld, P ..... *February*, 235
Kinsley, Carl ..... *June*, 1071
Lof, Eric A ..... *May*, 803
Lyman, James ..... *February*, 141; *November*, 1663
Macomber, Alexander ..... *February*, 165
Magnusson, C. Edward ..... *October*, 1599
Mahood, D. M ..... *June*, 861
Mailloux, C. O ..... *October*, 1427
Mauger, H. J ..... *May*, 693
McClenahan, Howard ..... *September*, 1379
McDowell, C. S ..... *June*, 861
McLain, R. H ..... *June*, 1009
Middleton, W. I ..... *June*, 987
Newbury, F. D ..... *January*, 1
Newell, F. H ..... *October*, 1583
Newton, Walter L ..... *June*, 849
Nims, F. D ..... *August*, 1147
Oschmann, William ..... *June*, 1027
Peek, F. W., Jr ..... *June*, 889; *December*, 1877
Pender, Harold ..... *March*, 385
Perry, Leslie L ..... *February*, 141; 197; *November*, 1663
Pigott, R. J. S ..... *June*, 953
Recklinghausen, M. von ..... *June*, 1049
Reed, Harrison P ..... *April*, 581
Roper, D. W ..... *May*, 733
Rosenblatt, Girard B ..... *August*, 1165
Rossman, Allen M ..... *February*, 141; *November*, 1663
Rowland, Arthur J ..... *September*, 1371
Rushmore, David B ..... *May*, 803

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Ryan, Harris J. ..... *June*, 937
Sorensen, Royal W. ..... *June*, 849
Sothman, P. W. ..... *February*, 201
Steinmetz, Charles P. ..... *January*, 13; *March*, 399
Stott, H. G. ..... *June*, 953
Swoboda, H. O. ..... *April*, 655
Thomas, Percy H. ..... *February*, 295
Tynes, T. E. ..... *June*, 1021
Underhill, Charles R. ..... *April*, 591
Whitehead, J. B. ..... *June*, 915
Whitney, E. F. ..... *December*, 1823
Woodbury, Edward ..... *September*, 1359
Woodruff, E. C. ..... *November*, 1689
Yardley, J. L. McK. ..... *November*, 1675

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# PROCEEDINGS

OF THE

## American Institute

OF

## Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol. XXXIII **January, 1914** No. 1


### Next A.I.E.E. Meeting, January 9, 1914

The 290th meeting of the A. I. E. E. will be held in the auditorium of the Engineering Societies Building, New York, January 9, 1914, at 8:15 p.m.

This will be a joint meeting of the American Institute of Electrical Engineers and the New York Sections of the American Electrochemical Society and the American Society of Mechanical Engineers. The subject of the meeting will be "power problems in the electrolytic deposition of metals," and three papers will be presented, as follows—(1) "Limitations of the Problem of Electrolytic Deposition," by Lawrence Addicks of the A. E. S., who will present a brief statement of the conditions imposed by practise in the electrolytic refining of copper as a typical process; (2) "The Mechanical Side of the Problem," by H. E. Longwell of the A. S. M. E., who will consider the application of gas and steam prime movers for driving generators of the required type; (3) "Sources of Direct Current for Electrochemical Processes," by F. D. Newbury of the A. I. E. E., discussing the design of the electrical equipment required in electrochemical work. The papers will be illustrated by lantern slides.

At the close of the technical session the meeting will adjourn to the Institute rooms on the 10th floor, where a smoker will be held and light refreshments served.

### A.I.E.E. Midwinter Convention

The second annual midwinter convention of the American Institute of Electrical Engineers will be held in the Engineering Societies Building, New York, February 25, 26 and 27, 1914, under the auspices of the Electric Power Committee.

The general subject of the meeting will be "electric power," and each of the sub-committees of this general committee will present papers on the special branch of this subject under its jurisdiction. The subdivisions of the subject are: (1) power stations, (2) power generation, (3) protective apparatus, (4) transmission, (5) distribution, (6) economics, and (7) engineering data. A full list of titles of the papers to be presented at this meeting is not available at this time, but a complete program of the convention will be published in the February issue of the PROCEEDINGS.

In addition to the technical sessions there will be some entertainment features, provided by the New York Reception Committee, which will also be announced in the February PROCEEDINGS.

### International Electrical Congress, San Francisco, 1915

The International *Electrical* Congress is to be held at San Francisco, September 13 to 18, 1915, under the auspices of the American Institute of Electrical Engineers by authority of the International Electrotechnical Commission,

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and during the Panama-Pacific International Exposition. Dr. C. P. Steinmetz has accepted the Honorary Presidency of the Congress. The deliberations of the congress will be divided among twelve sections which will deal exclusively with electricity and electrical practise. There will probably be about 250 papers. The first membership invitations will be issued in February or March, 1914.

Attention is drawn to the distinction between this Electrical Congress and the International *Engineering* Congress which will be held at San Francisco during the week immediately following the electrical congress. The engineering congress is supported by the Societies of Civil, Mechanical and Marine Engineers and by the Institutes of Mining and Electrical Engineers, as well as by prominent Pacific Coast engineers who are actively engaged in organizing it. This congress will deal with engineering in a general sense, electrical engineering subjects being limited to one of the eleven sections which will include about twelve papers, treating more particularly the applications of electricity in engineering work.

The meeting of the International Electrotechnical Commission will be held during the week preceding that of the Electrical Congress.

## Nominations for Institute Officers for 1914-1915

As provided in Section 18 of the Institute by-laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1914, by the petition or by the separate endorsement in writing, of not less than fifty members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1914. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available.

The officers to be elected are: a President and a Treasurer, for the term of one year each, three Vice-Presidents for the term of two years each, and four Managers for the term of three years each.

For the information of members, the full text of Section 18 of the by-laws, governing the proposal of candidates for nomination, is printed below:

"Sec. 18. In addition to the names of the incumbents of office, the Secretary shall publish on 'the form showing offices to be filled at the ensuing annual election in May,' provided for in Article VI, Section 30, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than fifty members, received by the Secretary of the Institute in writing by January 25 of each year.

"The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the January issue of each year's PROCEEDINGS, and shall be reproduced on the form above referred to."

## Section Territory

An important amendment to Section 51 of the Institute by-laws, recommended by the Sections Committee, was adopted by the Board of Directors at its meeting on December 12, 1913.

Under Section 51 the territory of Sections was limited to points within 60 miles of the meeting place. As the amount of financial support to which a Section is entitled from the Institute depends upon the number of Institute members in its territory, this limit proved to be unsatisfactory to a few of the Pacific coast Sections which desired to include certain towns beyond the 60-mile limit, but naturally tributary to the Sections concerned. The matter was brought up for discussion at the conference of Section delegates at the Cooperstown Convention last June, and the result is the present amendment.

The by-law as amended permits the extension of the territorial limits of any

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Section by the Board of Directors of the Institute, when in the judgment of the Board such extension is warranted by local conditions.

Amendments to the Institute by-laws become effective as soon as adopted, and the amended by-law is therefore in force. The text of Section 51 as amended is as follows:

Section 51. The territory of a Section shall include the locality naturally tributary thereto, but shall not include territory so remote or inaccessible that members cannot readily attend meetings. For the purpose of determining the maximum amount to which a Section is entitled under Section 60 of these By-laws, particularly Sub-Section (b) thereof, points more than sixty miles from the regular meeting place of the Section shall not be considered a part of that Section, except that, when special conditions warrant such action, additional territory within a reasonable distance may be authorized by the Board of Directors, upon application of the Executive Committee of the Section concerned, and the approval of the Sections and Finance Committees. If adjacent Sections are so situated that the 60-mile limit embraces common territory, then proximity shall govern the question as to which Section may claim such members as reside within this common territory.

## Present-day Tendencies and Problems

In a forceful and timely address delivered at the annual convention of the American Society of Civil Engineers in Ottawa, Ontario, last June, Professor George F. Swain, president of the Society, gave an admirable summary of the economic tendencies and problems of the times, and the relation of the engineer thereto.

The facts presented so strikingly by Professor Swain in his address are worthy of the thoughtful consideration, not only of engineers, but of thinking men in every walk of life. The address is broadly philosophical, and at the same time practical, and shows a keen insight into prevailing sociologic and economic conditions. It should be of especial interest to the rank and file of the Institute's membership in bringing to their attention the important part which the engineer can take in the adjustment of these conditions and the solution of the problems of the present day.

A limited number of reprints of Professor Swain's address is available, and until this supply is exhausted, a copy may be obtained upon application to Institute headquarters.

## Meeting at Stevens Institute

The members of the A. I. E. E. are cordially invited to attend a meeting at Stevens Institute of Technology, Hoboken, N. J., on Friday afternoon, January 9, 1914, at 3 o'clock.

The subject of discussion at this meeting will be "Public Service Corporations and Their Relations to the Public," and addresses will be made by a number of prominent engineers who are specially qualified to discuss this subject. Among the speakers are Dr. Alex. C. Humphreys, president of Stevens Institute, John W. Lieb, Jr., vice-president, New York Edison Company, James E. Sague, Public Service Commissioner 2d District, New York, and Newcomb Carlton, vice-president, Western Union Telegraph Company.

## Addresses Wanted

| Name | Former address. |
|---|---|
| G. S. Maltha, | Kentland, Ind. |
| H. E. Nichols, | 11½ N. College St., Schenectady, N. Y. |
| W. C. Parrish, | Walla Walla, Wash. |

Anyone who can give information that may assist in obtaining any of these addresses is requested to communicate with the Secretary of the Institute.

## Illuminating Engineering Society's Exhibit at Safety Exposition

The Illuminating Engineering Society had a miniature exhibition of lighting and illumination effects at the International Exposition of Safety and Sanitation in the Grand Central Palace, New York, December 11 to 20, 1913,

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which was awarded a grand prize. The exhibit consisted of a series of booths and a large collection of pictures, contrasting good and bad lighting in home, school, store and mill, and showing in a striking manner the importance of direction in illumination, and the vast difference between good use and misuse of light.

The entire exhibit, which was installed under the direction of a special committee of the society, is to be placed in the American Museum of Safety, in the Engineering Societies Building, New York, where it may be seen, free of charge, by the public.

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## Directors' Meeting, December 12, 1913

The Board of Directors of the Institute held its regular monthly meeting in New York on Friday, December 12, 1913, at 3:30 p.m.

There were present: President C. O. Mailloux, New York; Past-President Ralph D. Mershon, New York; Vice-Presidents A. W. Berresford, Milwaukee, Wis., S. D. Sprong, New York; Managers F. S. Hunting, Fort Wayne, Ind., W. S. Lee, Charlotte, N. C., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York, H. A. Lardner, San Francisco, Cal., B. A. Behrend, Boston, Mass., Peter Junkersfeld, Chicago, Ill., L. T. Robinson, Schenectady, N. Y.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $7,218.64, was ratified.

Upon the recommendation of the Sections Committee, Section 51 of the Institute by-laws, limiting Section territory to points within sixty miles of the meeting place of a Section, was amended so as to permit the Board of Directors to extend this territory in cases where such extension is warranted by conditions such as obtain with some of the Pacific Coast Sections.

Upon the recommendation of the Board of Examiners, the following action was taken upon pending applications for election and transfer:

Fifty-five applicants were elected Associates.

Eighty-four students were ordered enrolled.

The following applicants were elected to the grade of member: Stephen F. Briggs, Milwaukee, Wis.; Fred A. Bryan, South Bend, Ind.; J. W. Hissink, Kaiserdamm, Berlin, Germany; A. D. Hotson, Vancouver, B. C.; William P. Kennedy, New York; Sherman G. Peticolas, Omaha, Neb.; Samuel R. Pritchard, Blacksburg, Va.; Richard H. Whitehead, Pedro Miguel, C. Z.

The following Members were transferred to the grade of Fellow: H. A. Mavor, Glasgow, Scotland; William McLellan, Newcastle-on-Tyne, England.

The Standards Committee reported recommending the publication in the PROCEEDINGS of the preliminary report of the Joint Rubber Insulation Committee, an unofficial body representing various manufacturers and users of rubber compounds, which has been at work for two years preparing a standard specification and analytical procedure for 30 per cent *Hevea* rubber insulating compound. The report is printed in Section II of this issue.

The Secretary announced the following additional committee appointments by President Mailloux:

*Standards Committee:* W. A. Del Mar.

*Committee on Electrically Propelled Vehicles:* Ernest Lunn and Frank W. Smith.

*Sub-Committee on Transmission:* Victor H. Greisser.

*Sub-Committee on Distribution:* P. M. Lincoln.

*Local Representatives of the Board of Examiners* (As recommended by that Board): C. L. Cory, Berkeley, Cal.; R. F. Hayward, Vancouver, B. C.; H. H.

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Humphrey, St. Louis, Mo.; L. A. Herdt, Montreal, P. Q.; A. M. Schoen, Atlanta, Ga.; E. Leonarz, Monterey, Mex.; W. B. Jackson, Chicago, Ill.; J. F. Vaughan, Boston, Mass.

## A. I. E. E. Meeting in New York December 12, 1913

The 289th meeting of the Institute was held in the auditorium of the Engineering Societies Building, New York, on Friday evening, December 12, 1913.

President C. O. Mailloux called the meeting to order at 8:40 p.m., and introduced Mr. F. M. Farmer, who read his paper entitled *The Dielectric Strength of Thin Insulating Materials.*

Those who took part in the discussion of Mr. Farmer's paper and the general subject of insulating materials, were Messrs. F. W. Peek, Jr., Phillips Thomas, R. P. Jackson, C. E. Skinner, Henry W. Fisher, M. E. Tressler, E. B. Rosa, Clayton H. Sharp, John B. Taylor, A. E. Kennelly, D. B. Rushmore, H. M. Hobart, W. I. Middleton, C. F. Scott, and F. M. Farmer.

The meeting was then adjourned to the rooms of the Institute on the tenth floor, where light refreshments were served to the members and guests.

## Recommended for Transfer, December 9, 1913

The Board of Examiners, at its regular monthly meeting on December 9, 1913, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

### To the Grade of Fellow

BAUM, F. G., Consulting Engineer; Chief Engineer Hydraulic Construction, and General Superintendent Construction, Pacific Gas & Electric Co., San Francisco, Cal.

### To the Grade of Member

LITTLE, ARLINGTON P., Associate Professor of Electrical Engineering, Oklahoma A. & M. College, Stillwater, Okla.

PYLE, CLARENCE G., District Sales Agent, Standard Underground Cable Co., Los Angeles, Cal.

## Transferred to the Grade of Fellow December 12, 1913

The following were transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on December 12, 1913.

MAVOR, H. A., Electrical Engineer, Glasgow, Scotland.

MCLELLAN, WILLIAM, Merz and McLellan, Newcastle-on-Tyne, England.

## Members Elected December 12, 1913

BRIGGS, STEPHEN F., President, Briggs & Stratton Co., Milwaukee, Wis.

BRYAN, FRED A., President & General Manager, Indiana & Michigan Electric Co., 220 Colfax Ave., South Bend, Ind.

HISSINK, J. W., Member of Board of Directors, Bergmann-Elektricitatswerke Aktiengesellschaft; res., Kaiserdamm 36, Berlin W., Germany.

HOTSON, A. D., Senior Member, Hotson & Gillies, Vancouver, B. C.

KENNEDY, WILLIAM P., Consulting Engineer, 1790 Broadway; res., Hotel Flanders, 135 W. 47th St., New York, N. Y.

PETICOLAS, SHERMAN G., Consulting Electrical & Mechanical Engineer, Suite 209-15 Woodmen of the World Bldg., Omaha, Nebr.

PRITCHARD, SAMUEL REYNOLDS, Professor of Electrical Engineering, Virginia Polytechnic Institute, Blacksburg, Va.

WHITEHEAD, RICHARD HENRY, Testing Engineer, Isthmian Canal Commission, Pedro Miguel, C. Z.

Total 8.

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**Associates Elected December 12, 1918**

ALDEN, FREDERICK ARTHUR, Assistant Mechanical Superintendent, Wm. Filene's Sons Co., Boston; res., 60 Gorham St., Cambridge, Mass.

BAKER, GEORGE MILFORD, Engineer, Power & Mining Engineering Dept., General Electric Co., Schenectady, N. Y.

BARTON, LOWRIE CHILDS, JR., Salesman, Westinghouse Electric & Manufacturing Co., Cincinnati, Ohio.

BIRD, VIGGO E., Manager, Connecticut Power Co., 33 Union St., New London, Conn.

BLYTHE, W. E., Engineer Salesman, Crocker-Wheeler Co.; res., The Leavenworth Apts., 615 James St., Syracuse, N. Y.

BOSE, SURENDRA NATH, Electrical Engineer, Bombay, India.

BOTTINELLI, M. J., Electrical Foreman, Bunker Hill & Sulivan Mining & Con. Co., Kellogg, Idaho.

CASSIDY, PERRY ROGAN, Instructor in Thermodynamics and Power Plant Design, State University of Kentucky, Mechanical Hall, Lexington, Ky.

CHAKRAVARTI, P. C., Student Demonstrator, Indian Institute of Science, Bangalore, India.

CHARLAND, JOS., General Foreman, Canadian Copper Co., Copper Cliff, Ont.

COMINS, EDWARD IRVING, Electrical Department, Worcester Polytechnic Institute; res., 12 Hawthorn St., Worcester, Mass.

CRIPPEN, CHARLES IVAN, Superintendent Light & Power, Brooke Electric Co., 611-16 German Bank Bldg., Wheeling, W. Va.

DAINTY, W. REGINALD, Electrical Engineer, Union Electric Co. Ltd., Johannesburg, S. Africa.

DALAL, S. N., Electrician, College of Engineering; res., 14 Main St., Poona, India.

DEBATS, CHARLES J., Construction Engineer, Seymour Power Co., Belleville, Ont.

FIELDING, H. W., Superintendent of Construction, Western Canada Power Co. Ltd., Stave Falls; res., Ruskin, B. C.

FOLLANSBEE, J. A., Erecting & Construction Engineer, Canadian Copper Co., Copper Cliff, Ont.

FRIDEN, VICTOR E., Switchboard Engineering Dept., General Electric Co.; res., 170 McClellan St., Schenectady, N. Y.

GILLER, FREDERICK STANLEY, Assistant Plant Engineer, European Organization, Western Electric Co., North Woolwich, London, England.

HADDAWAY, THOMAS S., Engineering Draftsman, Union Electric Light & Power Co., St. Louis; res., 322 Clark Ave., Webster Groves, Mo.

HART, ALBERT D., Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 841 Holland Ave., Wilkinsburgh, Pa.

HERRLICH, HERMANN W., Engineer, General Electric Co., Schenectady; res., 143 Riverside Ave., Scotia, N. Y.

HOFFMANN, CHARLES BARTH, Assistant in Electrical Engineering, Harvard University, Cambridge, Mass.

HOLLEY, ROBERT C., Power Salesman, Georgia Railway & Power Co., Atlanta, Ga.

HORTON, W. H., JR., Sales Engineer, General Electric Co., Denver, Colo.

JOHNSON, WILLIAM F., Instructor of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

KELLEY, WALTER L., Student at Tufts College Electrical Engineering School; res., 30 Cleveland St., Arlington, Mass.

KELLOGG, W. D., Sales Engineer, Industrial Power Dept., Consolidated Gas, Electric Light & Power Co.; res., 1401 Linden Ave., Baltimore, Md.

LANGAN, T. R., Sales Department, Westinghouse Electric & Manufacturing Co., 121 E. Baltimore St., Baltimore, Md.

MANYPENNY, JOSEPH P., President & Manager, Engineering Equipment Co., 1011 Chestnut St., Philadelphia, Pa.

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McCLELLAN, W. D., Engineer, Beaver River Power Co., Casper, Wyo.

McGEEHAN, CHAS. A., Instructor, Villanova College, Villanova, Pa.

McNEAL, R. L., Consulting Engineering Dept., General Electric Co.; res., 23 Westminster St., Pittsfield, Mass.

MELVIN, HOWARD L., Instructor in Electrical Engineering, State College of Washington; res., 312 Howard St., Pullman, Wash.

MERRIHEW, ERNEST H., Chief Electrician, Brunet Falls Mfg. Co., Cornell, Wis.

NICHOLS, HAROLD WILLIAM, Assistant Professor Electrical Engineering, Armour Institute of Technology, Chicago, Ill.

OPPENHEIM, BEN J., Designing Electrical Engineer, American Engine & Electric Co., Bound Brook, N. J.

PERRY, E. R., Draftsman, Puget Sound Traction, Light & Power Co.; res., Waldorf Hotel, 7th & Pike St., Seattle, Wash.

PIGOTT, REGINALD J. S., Mechanical Construction Engineer, Interborough Rapid Transit Co., 600 W. 59th St., New York, N. Y.

POWELL, ALVIN LESLIE, Assistant in Illuminating Engineering, General Electric Co., Harrison; res., 241 N. 11th St., Newark, N. J.

ROSS, DAVID, JR., Electrical Engineering Dept., Toronto Power Co., 10 Adelaide St. East, Toronto, Ont.

SCHOLER, ALBERT GEORGE, Chief Tester, Edison Storage Battery Co., Orange, N. J.

SHIRLEY, ERNEST ROXFORD, Electrical Superintendent, Canadian Exploration Co., Ltd., Naughton, Ontario.

SIMPSON, CLAUDE W., Insurance Engineer, Marsh & McLennan, Room 2037, 175 W. Jackson Blvd., Chicago, Ill.

STAEGEMANN, EUGENE, Designer of Dynamos, Knapp Electrical Co., New York; res., Suffern, Rockland Co., N. Y.

STAFFORD, HARRY E., Construction Engineer, Canadian General Electric Co., Port Arthur, Ont.

STAPLES, ROBERT TYLER, Telephone Engineer, Western Electric Co.,463 West St., New York, N. Y.

TOUCHE, ARTHUR STANLEY, Commonwealth Edison Co., 120 W. Adams St., Chicago, Ill.

TRAYNOR, PETER W., Electrical Engineer, Davis Coal & Coke Co., Thomas, W. Va.

TRUST, HUMPHREY G., Electrical Engineer, Companhia Sul-American de Electricdade, Caixa de Correio 1138, Rio de Janeiro, Brazil.

WATTS, EGBERT M., Assistant Electrical Engineer, Montreal Tunnel & Terminal Construction Co.; res., 357 Esplanade Ave., Montreal, Quebec.

WHITE, LEO A., Electrical Superintendent, Muskogee Gas & Electric Co., Muskogee, Okla.

WILDER, WILLIAM J., Assistant Superintendent, Electrical Construction, Crocker-Wheeler Co., Ampere; res., 384 N. Grove St., East Orange, N. J.

WOHRA, HAR DAS, Student in Electrical Engineering, State University of Arkansas; res., 200 W. Dixon St., Fayetteville, Ark.

YOSHIMI, SEIICHI, Electrical Engineer, Inawashiro Hydro-Electric Power Co., Marunouchi, Tokyo, Japan.

Total 55.

## Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 30, 1914.

Allen, L. W., Spokane, Wash.

Anderson, A. R., Columbus, Ohio.

Armstrong, R. S., Chicago, Ill.

Atwood, E. H., Olean, N. Y.

Bartlett, C. C., Corona, Cal.

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Beck, W. H., Baltimore, Md.
Black, C. D., Pittsfield, Mass.
Bonvouloir, L., Boston, Mass.
Bopp, C. D., Chicago, Ill.
Brackett, H. H., New York, N. Y.
Brewbaker, M. W., Gatun, C. Z.
Bucholz, C. D., Philadelphia, Pa.
Burgoon, C. E., Washington, D. C.
Burnham, G. B., San Francisco, Cal.
Burrows, C. W. (Member), Washington, D. C.
Carolan, E.A. (Member), New York, N.Y.
Carr, E. C., Seattle, Wash.
Chernyshoff, A., St. Petersburg, Russia
Clement, M. F., New Rochelle, N. Y.
Crawford, D. K., Topeka, Kans.
Dietrich, F. W., Eugene, Ore.
Dyer, W. H., Billings, Mont.
Dyer, A. B., San Miguel Allende, Mex.
Eby, E. E., E. Pittsburgh, Pa.
Embree, C. J., Culebra, C. Z.
Fawcett, C. D., Philadelphia, Pa.
Fenley, W. H., Cristobal, C. Z.
Flowers, J.B. (Member), NewYork, N.Y.
Galbraith, F. E., New York, N. Y.
Garthorne, G. E., San Francisco, Cal.
Gfrorer, A.H., West New Brighton, N.Y.
Giles, G. S., Philadelphia, Pa.
Goetz, W. W., Philadelphia, Pa.
Hastings, R., Boston, Mass.
Heath, H. T., East Pittsburgh, Pa.
Horton, B. D., Detroit, Mich.
James, H., Bluefield, W. Va.
Jensen, J. O., Los Gatos, Cal.
Jeter, F. A., Spokane, Wash.
Jones, F. S., Orono, Maine.
Johnston, A. L., Plymouth, Pa.
Kaylor, P. P., Bellingham, Wash.
Kegerreis, R., Philadelphia, Pa.
Khopp, J. B., Schenectady, N. Y.
Kingsland, R. L. (Member), Fairmont, W. Va.
Kinsman, R. E., New York, N. Y.
Kriegsmann, A. E., Schenectady, N. Y.
Krone, R. H., Norwood, Ohio.
Kuehne, J. H., Buffalo, N. Y.
Kunkel, C. D., Spokane, Wash.
Kurtz, F. W., Henry Clay, Del.
Kyes, L. C., Gatun, Panama.
Larsen, C. J., Hazleton, Pa.
Lightbody, J. N., Calgary, Alta.
Lowe, H. L. (Member), St. Louis, Mo.
MacMurchy, H. G., Toronto, Ont.
Martin, W. H., New York, N. Y.
McClellan, L. N., Phoenix, Ariz.
McGuire, W. P., Chicago, Ill.
Meyerherm, C. F., Hoboken, N. J.
Myrick, J.C. (Member), Pedro Miguel, C.Z
Nims, S. A., Concord, N. H.
Nolte, R. W., Mira Flores, C. Z.
Overocker, R. H., New York, N. Y.
Parker, R. I., Schenectady, N. Y.
Parsons, D. E., Pittsburgh, Pa.
Pearson, G. A., Ampere, N. J.
Powers, A. R. (Member), Potsdam, N.Y.
Richey, A. L., New York, N. Y.
Sams, F. V., Milwaukee, Wis.
Schuman, E. S., Cambridge, Mass.
Scriven, E. O., New York, N. Y.
Simonson, G. M., Sacramento, Cal.
Smith, D. L., Chicago, Ill.
Stair, J. S., Jr., E. Pittsburgh, Pa.
Stalker, J. W., St. Boniface, Man.
Stern, M. R., Chattanooga, Tenn.
Stewart, C. R., Pittsfield, Mass.
Swenson, T., Jr., St. Paul, Minn.
Taylor, H. V. S., E. Pittsburgh, Pa.
Town, T., Rapid City, Manitoba.
Van Norman, C. P., Toronto, Ont.
Vosmaer, A. (Member), Brooklyn, N. Y.
Walker, J. P., Atlanta, Ga.
Walter, R. E., Waterloo, Ia.
Washburn, F. S., Nashville, Tenn.
Wenk, M., Stockton, Calif.
Williams, R., Palmerton, Pa.
Wirt, C., Germantown, Phila., Pa.
Yabe, T., Osaka, Japan.
Ziehn, R. S., Chicago, Ill.
Total 91.

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**Students Enrolled December 12, 1918**

6142 McLay, A. D., Univ. of Michigan.
6143 Norton, J. R., Univ. of Michigan.
6144 Rogers, F.E., Jr., Stevens Inst. Tech.
6145 Baxter, H.C., Swarthmore College.
6146 Bridge, E. H., Ohio North. Univ.
6147 Asire, H.W., Purdue University.
6148 Howerton, J., Purdue University.
6149 Bryan, F. A., Jr., Purdue Univ.
6150 Moore, C. L., Purdue University.
6151 Thomas, E.M., Purdue University.
6152 Rigg, R. H., Purdue University.
6153 Norton, O.P., Purdue University.
6154 Carter, E.L., Purdue University.

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6155 Pyke, D. C., Purdue University.
6156 Ely, G. B., Purdue University.
6157 Mitchell, D. C., Purdue Univ.
6158 Davison, A.C., Purdue University.
6159 Magley, A.J., Purdue University.
6160 Beal, H.C., Purdue University.
6162 Gibbon, C.O., Purdue University.
6163 Miessner, B.F., Purdue Univ.
6164 Beyer, J.W., Wash. State Coll.
6165 Halle, S., Cornell University.
6166 Gooch, E. P., Cornell University.
6167 Goldman, B.P. Cornell University.
6168 Gibson, W.A., Cornell University.
6169 Fry, J. R., Cornell University.
6170 Street, L.N., Syracuse University.
6171 Cooper, S.M., Syracuse University.
6172 Nolte, A.C., Columbia University.
6173 Mullen, F. B., Columbia Univ.
6174 Huxley, R.D., Mass. Inst. Tech.
6175 Nash, J.F., A.&M. Coll. of Texas.
6176 Lockett, W.C., A.&M. Coll. Texas.
6177 Kristek, G.H., A.&M. Coll. Texas.
6178 Jones, W.T., A.&M. Coll. of Texas.
6179 Richtmyer, L.D., Wentworth Inst.
6180 Peterson, L.W., Wentworth Inst.
6181 Cooksey, D., Yale University.
6182 Hodgkins, H.C., Univ. of Maine.
6183 Dunn, G.C., University of Kansas.
6184 Spurgeon, J. H., Univ. of Missouri.
6185 Thompson, R.G., Univ. of Missouri.
6186 Crump, L. L., Univ. of Missouri.
6187 Anderson, F.W., Univ. of Missouri.
6188 Brehman, L.W., Ohio North. Univ.
6189 Chapman, F.E., Univ. of Maine.
6190 Davis, W.K., A.&M. Coll. of Texas.
6191 Groginski, P., A.&M. Coll. of Texas.
6192 Levy, D.H., A.&M. Coll. of Texas.
6193 Pickens, D.B., A.&M. Coll. Texas.
6194 Scrames, G.G., Univ. of Michigan.
6195 Rogers, C.M., Univ. of Michigan.
6196 Lester, C. B., Univ of Michigan.
6197 Cutler, H. D., Univ. of Michigan.
6198 Harding, B., Univ. of Michigan.
6199 Park, C.S., Univ. of Michigan.
6200 Weilbacher, W.C., Univ. of Mich.
6201 Conklin, H.S., Jr., Lafayette Coll.
6202 Parker, K., Univ. of Illinois.
6203 Irwin, V.H., Univ. of Minnesota.
6204 Mann, R. F., Case School App. Sci.
6205 Eghiyan, E.S., Union College.
6206 Markham, A.J., Stevens Inst. Tech.
6207 Anderson, E. H., Union College.
6208 Hausmann, V.F., Case Sch. App. Sci.
6209 Strathy, R. L. A., McGill Univ.
6210 Lahrmann, C., Colorado State Col.
6211 Isley, P. T., Purdue University.
6212 Gamble, L.R., Purdue University.
6213 Henline, H.H., University of Ill.
6214 Morse, V. F., Throop Poly. Inst.
6215 Jansen, P.C., Iowa State College.
6216 Anderson, E. G., Iowa State Coll.
6217 Scarborough, H.A., Iowa State Coll.
6218 Holmes, W. M., Throop Poly. Inst.
6219 Rogers, C.T., Swarthmore College.
6220 Murdock, P. F., Yale University.
6221 Metzner, M.W., Case Sch. App. Sci.
6222 Berry, E.H., University of Illinois.
6223 Donahoe, J. T., University of Ill.
6224 Burnett, Wm., Jr., Univ. of Illinois.
6225 Scott, E.S., University of Illinois.

## Past Section Meetings

### BALTIMORE

The November meeting of the Baltimore Section was a dinner held at the City Club, on the evening of the 21st. The subject for discussion was: "Engineering Education, with Special Reference to the New Department at Johns Hopkins." Professor J. B. Whitehead, chairman, introduced the subject, followed by Mr. J. B. Scott, Prof. C. J. Tilden, Prof. C. C. Thomas, Prof. S. N. Taylor, Mr. A. S. Loizeaux and Mr. J. C. Distler.

Particular emphasis was laid by the speakers on a training which teaches a man to think rather than a too-specialized training in a particular line of engineering. The importance of ability to express one's self clearly and concisely, not only in written language but also in diagrams and other modes of expression, was emphasized.

All those taking part in the discussion agreed as to the need of a broad training including the study of English and a general cultural education to enable the engineer to hold his own with the cultured man, the lawyer, the financier or the business man, and thus make the most of his life.

Twenty-seven members and guests were present.

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### Boston

The Boston Section of the Institute participated in a joint meeting on November 19 in Tremont Temple with the Boston Sections of the American Society of Civil Engineers and the American Society of Mechanical Engineers. Mr. James W. Rollins, president of the Boston Society of Civil Engineers, presided, and there was an attendance of 50 at the meeting.

A paper was presented by Mr. John W. Alford, of Chicago, on "Engineering Lessons from the Ohio Floods."

### Chicago

A meeting of the Chicago Section of the A. I. E. E. and the Electrical Section of the Western Society of Engineers was held in Fullerton Hall on Wednesday evening, October 29. Dr. C. P. Steinmetz presented a paper entitled *Instability of Electric Circuits*, which is printed in Section II of this issue of the Proceedings. About 430 members and guests were present at this meeting.

### Cleveland

A meeting of the Cleveland Section was held on December 1, at the plant of the Wellman-Seaver-Morgan Company, and Mr. H. L. Wallau presided. Mr. Charles W. Larner of the Wellman-Seaver-Morgan Company presented a paper entitled "The Keokuk, Iowa, Hydroelectric Plant of the Mississippi River Power Company." The paper was illustrated with lantern slides.

The total attendance was 73.

### Indianapolis-LaFayette

The first meeting of the Indianapolis-LaFayette Section held at LaFayette this year was held on November 11, in the lecture room of the Electrical Engineering Building at Purdue University. The Purdue University Branch of the A. I. E. E. joined with the Section in this meeting.

Professor C. Francis Harding of Purdue University presided, and the total attendance was 83. Mr. Guy M. Laird addressed the meeting on "Some Observations and Problems Connected with Electrical Power Supply to Mines and Smelters." The speaker discussed the uses of electricity in mines and smelters and the many problems connected with the generation, transmission, and utilization of electrical energy for this work.

The desirability of continuity of service was emphasized. A ten-minute shut-down of the blower motors connected with a smelting furnace will interrupt the output of the furnace for twenty-four hours. Lightning and snow slides are common causes of interruption of service. Lightning alone has caused as many as seventeen interruptions in one month. The speaker pointed out the use of graphic meters in checking the power demands on the various machines and the efficiency of the men in handling the machines. The problems connected with the handling of men were also discussed at some length.

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The next monthly meeting of the Section was held on December 5 at the Indianapolis Chamber of Commerce, and there were present as special guests a number of the local members of the American Chemical Society. Chairman O. S. More presided, and the total attendance was 70.

Mr. Richard Fleming, manager of the Fairbanks-Morse Electrical Manufacturing Company, gave a talk on the subject of "Applications of Electrochemistry to Industry," and considered both electrolytic actions in solutions and chemical actions in the electric furnace. Mr. Fleming traced briefly the electrochemical processes used in the obtaining from the native ores and in the refining of aluminum, copper, gold, silver, steel and iron, silicon, lead, nickel, zinc, graphite, sodium, and phosphorus, those used in the commercial manufacture of calcium carbide, artificial nitrogenous fertilizers, carborundum, and ammonia, and those used in commercial electroplating, including galvanizing, electrotyping, and

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the preparation of phonograph records. Mr. Fleming also referred briefly to Moissan's work in connection with the artificial diamond and to the efforts which have been made to obtain diamonds on a larger scale.

Following the talk there was an extended discussion, in which members of both the Institute and the American Chemical Society freely participated.

### Los Angeles

The Los Angeles Section held its regular monthly meeting on November 24, in the Music Hall, Blanchard Building. Chairman E. R. Northmore presided.

A paper entitled "Electricity and the Fire Hazard," was presented by Mr. J. H. Montgomery, dealing with the National Code rules and the hazards from the use of electricity. The paper was illustrated.

The paper proved to be of great interest and brought out considerable discussion as to the manner in which all men connected with the electrical business could reduce the fire hazard by coöperation.

The total attendance at this meeting was 67.

### Lynn

The Lynn Section held a meeting on November 28, in Burdett Hall. The speaker of the evening was Mr. D. L. Galusha, engineer of electrical installation of the Keokuk development for the Stone and Webster Corporation, who took for the subject of his lecture "The Hydroelectric Development at Keokuk, Iowa."

With the aid of a large number of lantern slides Mr. Galusha made clear to his audience that the plant at Keokuk, which is the largest water-power development in the world, was installed in the face of the greatest difficulties imaginable. The Keokuk power plant is located on the Mississippi River, some thousand miles above its mouth, near the boundaries of Iowa, Missouri and Illinois, and at a point about the center of the United States. At this point the conditions permit of developing something like 200,000 h.p. The entire cost of the plant from the beginning to its final construction is estimated to be in the neighborhood of $25,000,000. In many features the work necessary was much on the scale of the work that has been done on the Panama Canal, and Mr. Galusha described in detail the construction of the dam across the river, where the currents were very strong, and the construction of the plant itself, intended to supply the city of St. Louis with all the power needed. Active construction of the dam was commenced in the spring of 1911, and the entire structure was completed in May, 1913. As the result of the construction of the dam and the holding back of the waters of the river at this point, a lake was formed 65 miles long and ranging in width from one to two miles.

The transmission system consists at present of two 110,000-volt circuits south to St. Louis, two 11,000-volt circuits north to Burlington and four 11,000-volt circuits to points near the plant.

The subject for this meeting aroused great interest among the members of the Lynn Section, which was evidenced by the record-breaking attendance of 427. Chairman E. R. Berry presided and introduced Mr. Galusha.

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Mr. J. A. Orange of the General Electric research laboratory at Schenectady, N. Y., addressed the next meeting of the Lynn Section, on December 3, on the subject of "Gas-Filled Tungsten Lamps." Professor Elihu Thomson introduced Mr. Orange to the meeting, first giving a short history of the development of the incandescent lamp from the time of the first experiments with the carbon lamp in the 70's to the present highly efficient tungsten filament lamps.

Professor Thomson explained the work of Dr. Coolidge, whereby the tungsten metal, which was exceedingly brittle, was rendered extremely ductile and capable of being drawn to a fine

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wire. He cited instances where single lengths of 16,000 feet had been drawn without breaking. In the past the vacuum lamp has been the common article of commerce, but the time has now arrived when the introduction of gas, nitrogen or ether bids fair to revolutionize the lamp industry.

Mr. Orange began his address by stating that the value of lamps was measured by three conditions—efficiency, watts per candle and life. Lamps should be renewed when the candle power drops to 80 per cent of the normal output. The cost of running a lamp which has fallen off 20 per cent in output, still remains the same as when first put in service; this, of course, is not good business. Investigation disclosed the fact that in general the failure of tungsten lamps was caused either by the breakage of the filaments or by the blackening of the bulb. The breakage of the filaments in the early days was a serious factor, but at present the wire is so strong and ductile that a blow is more likely to break the glass bulb than the filament.

The life of the lamps is now practically determined by the length of time required for the blackening of the bulb sufficiently to cut down the light so that the output is only 80 per cent of its original value. The real cause of the blackening of the bulb has been proved to be evaporation of the filament due to its high temperature. The minute particles of tungsten are projected against the glass and this is rendered easier on account of the fact that the filament is placed in a vacuum and that there are practically no gas molecules to retard the flight of these particles.

This discovery led to the attempts to introduce various gases into the bulb, which would tend to retard the projection of these particles. Another method has been the changing of the location of the deposit by means of convection currents in gases so that the bulb opposite the filament is not blackened, but the deposit being located at a point above, the illumination is not affected to any great degree.

Mr. Orange exhibited, in operation, several types of the new lamps, and the brilliance of the light was a revelation to the electrical engineers present. He also showed one of the new lamps designed to show daylight color. After his lecture, Mr. Orange answered questions and discussed technical points with the engineers present.

Chairman Berry presided at this meeting, at which the attendance was 318.

### Mexico

Members of the Mexico Section, and their guests, to the number of 26, held a dinner meeting at Sylvain's Restaurant on November 28. Instead of having a technical paper presented, an experience meeting was held. Many of the engineers described unusual and humorous experiences they had met with in electrical work in various parts of the globe, and this program proved to be of great interest. Chairman Norman Rowe presided.

### Minnesota

The regular monthly meeting of the Minnesota Section was held in the Ryan Hotel, St. Paul, on Monday evening, November 17. The meeting was preceded by the customary dinner, there being 24 members and guests present.

At the eight o'clock session 35 members and visitors were present. The meeting was opened by Chairman W. T. Ryan, who introduced the first speaker, Mr. John Pearson, of the St. Croix Water Power Company.

Mr. Pearson, with the aid of the stereopticon, gave a detailed description of a waterwheel governor of his own invention. This governor is electrical in its operation and contains a number of novel features, among which are so-called "floating primary contactors," and a self-adjusting, compensating regulator. With this governor the most delicate regulation is possible and racing is prevented. Simple

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means of adjusting are provided to accommodate various loads.

The next speaker, Professor George D. Shepardson of the University of Minnesota, discussed "Resistance of Ground Connections," bringing out a number of interesting points. It was shown that the ground resistance is practically constant beyond 100 radii of the ground plate on a spherical basis. It was also shown that the nature of the soil is not as important as has been believed, but that much more depends upon the degree of compactness of the soil in contact with the ground plate.

The effect of polarization, as well as aging, was discussed by Mr. L. D. Stenger, and local or surface grounds by Mr. Dustin. A general discussion followed.

PHILADELPHIA

The 94th meeting of the Philadelphia Section of the A. I. E. E. was held in conjunction with the Philadelphia Section of the Illuminating Engineering Society, at the Engineers' Club, on December 8. Messrs A. R. Cheyney and G. A. Hoadley were the presiding officers.

The papers of the evening were: "Railway Car Lighting," by G. E. Hulse; "Brightness Measurements vs. Illumination Measurements," by Herbert E. Ives, Ph.D.; and "The Mercury Vapor Quartz Lamp," by M. B. Buckman. The discussion which followed the reading of the papers was participated in by Messrs. Porter, Bond, Goodwin, Hoadley, Hering, Serrell, Ives, Hulse and Buckman.

An exhibition of the mercury vapor quartz lamp had been arranged, and Mr. Calvert of the Illuminating Engineering Society showed a new fixture, arranged to give what was stated to be the equivalent of daylight. He had also set up an apparatus for the sterilization of water by means of the mercury vapor arc, which was shown and described by Mr. Stillwell.

PORTLAND, ORE.

The Portland Sections of the American Institute of Electrical Engineers and the National Electric Light Association held a meeting on December 2, in the assembly hall of the Hawthorne Building. Mr. E. A. West, chairman of the N. E. L. A. Section, presided. The total attendance was 130.

Mr. O. B. Coldwell, superintendent of light and power of the Portland Railway, Light and Power Company, read a paper entitled "Regulative Measures Affecting Public Utilities."

After the meeting was adjourned the members enjoyed an entertainment. Refreshments were provided.

ST. LOUIS

On October 22, the 84th meeting of the St. Louis Section was held in one of the private dining-rooms of the American Hotel. Following the regular custom of the Section for the opening meeting of each season, this one combined a dinner and social hour with such business as was due to come before the Section.

The main business of the evening was a detailed account of what took place at the recent convention at Cooperstown, given by Chairman F. J. Bullivant.

During the hour following the dinner Mr. Val A. Fynn gave an interesting account of some recent European installations seen by him during his trip of the past summer.

At this meeting the members learned with much regret of the death of Associate John A. Kraeuchi, on Sunday, October 19, following a brief illness. A special committee was appointed to draft resolutions to be spread upon the Section's minutes and transmitted to the family of the deceased.

The total attendance was 18. Chairman F. J. Bullivant presided.

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The eighty-fifth meeting of the Section was held Nov. 12, at the rooms of the Engineers' Club of St. Louis. This was a joint meeting with the Associated Engineering Societies of St. Louis, held under the auspices of the St. Louis Section of the A. I. E. E.

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At these joint meetings it is the custom of this Section to dispense with executive business, and on this occasion Chairman F. J. Bullivant, who presided, at once introduced Professor Morgan Brooks, of the University of Illinois.

Under the title "Effective Illumination of Interiors" those present heard Professor Brooks deliver a very instructive paper, of general as well as technical interest, relating to modern methods of interior lighting. The remarkable efficiency of the nitrogen-filled tungsten lamp was illustrated through a comparison of a 1000-watt nitrogen-filled lamp with the standard tungsten lamps in use in the Engineers' Club rooms. The tendency toward better illumination rather than cheaper illumination was touched upon as one of the results not universally expected to follow the introduction of the higher efficiency lamps.

The nomenclature of photometry, with reference to the present looseness of definitions, received attention, and certain improvements were suggested. Professor Brooks dwelt more especially, however, upon the lighting of interiors, pointing out general principles whereby practical as well as artistic lighting is obtainable. The direct, indirect and semi-indirect methods have their individual fields of usefulness. Artistic effects arranged by the architect are frequently augmented by correct illumination, but are too often subdued through incorrect lighting.

Members and guests participated in the general discussion that followed. The total attendance was 77.

### San Francisco

The November meeting of the San Francisco Section was postponed to December 5, at which time Mr. R. W. Van Norden gave a very interesting and instructive paper on the Pacific Gas and Electric Company's Drum development in the Sierra Mountains, with reference particularly to the economic conditions governing the engineering design.

The meeting was held in Native Sons Hall, and the total attendance was 86. Chairman A. H. Griswold presided.

### Schenectady

The Schenectady Section held a discussion meeting on November 18, in the Edison Club Hall, at which the total attendance was 350. Chairman George H. Hill presided.

The principal subject for discussion was "The Butte, Anaconda and Pacific 2400-volt Electrification," and the principal speakers were Messrs. G. H. Hill, A. H. Armstrong, J. J. Linebaugh, R. Stearns, S. T. Dodd and C. J. Hixson. Many lantern slides were shown, and moving pictures of the Butte, Anaconda and Pacific Railway and of Montana mining and smelter scenes.

### Seattle

The Seattle Section held a meeting on November 18, in the Chamber of Commerce. Chairman J. D. Ross presided, and the total attendance was 41.

As this was the annual business meeting, the secretary made his financial report, and the members then proceeded to the election of officers for the year, to take office at the January meeting. Mr. S. C. Lindsay was elected chairman and Mr. E. A. Loew secretary.

Mr. Lindsay presented the paper of the evening, entitled "The Use of Protective Relays on Power Systems."

The paper was discussed by Messrs. Harisberger, Terrell, Magnusson, Miller, Ross and Crawford.

### Toledo

The meeting of the Toledo Section on December 5 was held at the Toledo Filtration Plant.

Chairman George E. Kirk introduced the speaker, Mr. Goodwillie, superintendent and chief chemist of the Toledo Filtration Plant. The speaker outlined the plant in general by means of a chart and described the chemical and mechanical methods of filtration used at the

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plant, which has a daily capacity of thirty million gallons. After the lecture and discussion, which was held in the laboratory, the rest of the plant was visited. The total storage capacity of the plant is about twenty million gallons.

A very interesting evening was spent and the speaker was kept busy with questions and discussions.

Fifty-four members and visitors attended the meeting.

TORONTO

Members of the Toronto Section attended an address by Mr. S. P. Brown, chief engineer of the Canadian Northern Montreal Tunnel and Terminal Company, on the evening of November 17, at the University of Toronto. The meeting in reality was held under the auspices of the University of Toronto Engineering Alumni Association, but they thoughtfully extended an invitation to attend this meeting to the members of the Toronto Section, which was very gratefully accepted.

Mr. Brown presented a most interesting address on the engineering work in connection with the Montreal tunnel and terminal and illustrated his paper with a great many lantern slides.

URBANA

A meeting of the Urbana Section was held on November 10, in the electrical engineering laboratory of the University of Illinois. The chairman, Professor Morgan Brooks, presided, and the total attendance was 67.

Professor Brooks gave a demonstration of the new high-efficiency tungsten lamp and discussed the Institute paper of Dr. Langmuir on *The Blackening of Tungsten Lamps and Methods of Preventing It.*

WASHINGTON, D. C.

The Washington Section held a meeting on November 11, in the Chesapeake and Potomac Telephone Building, which was attended by 46 members and visitors. Chairman H. C. Eddy presided.

A paper was presented by Mr. Norman Macbeth, editor of *The Lighting Journal*, on "The Growing Recognition of Illumination." Among other things he pointed out the important bearing of lighting upon values of real estate, an effect greatly in excess of the cost of the lighting. He also mentioned the new lamps which would reduce this cost still further. A number of slides were shown to illustrate typical installations of both good and bad lighting.

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The next meeting of the Section was held on December 9, with a total attendance of 53.

Dr. E. B. Rosa was elected to represent the Section as vice-president of the Washington Academy of Science.

Mr. W. J. Eck, electrical engineer of the Southern Railway, read a paper on "Railway Block Signaling."

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## Past Branch Meetings

ARMOUR INSTITUTE OF TECHNOLOGY

A meeting of the Armour Institute of Technology Branch was held on October 29. A paper was presented by Messrs. M. B. Stecher and C. L. Witzel on "A-C. and D-C. Signaling Devices Used for Railway Service."

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At a meeting of the Branch on November 12 a paper on "Station Grounds" was presented by Mr. A. B. Gates, engineer for the Sanitary District of Chicago.

UNIVERSITY OF CALIFORNIA

The University of California Branch held a meeting on November 12, when papers on "Storage Batteries" were presented by Messrs. L. F. Moullet and G. W. Thernen.

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The next meeting of the Branch was held on November 26, when Messrs. C. Z. Yost and Guy Barker presented a paper on "Illumination."

At this meeting the International Electrical Congress to be held in San Francisco in 1915 was discussed, and

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it was also decided to have a banquet in San Francisco on December 13, 1913, and to invite the Stanford University Branch to attend.

### University of Cincinnati

A meeting of the University of Cincinnati Branch was held on November 18. Mr. C. A. Powell, of the Johnson-Kennedy Electric Company, presented a paper on "Incandescent Lamps."

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At the meeting of the Branch on December 9 the speaker was Mr. Nelson, city electrician of Cincinnati. His subject was "The Use of Electricity by the City."

### Clemson College

At the meeting of the Clemson College Branch on November 17, two of the members, Messrs. H. E. Chambliss and F. H. McDonald, gave brief accounts of their experiences while working in the summer for the Public Service Corporation of New Jersey. Mr. Chambliss spoke particularly of transformer installation. Other members of the Branch then presented reviews of current electrical journals.

### University of Colorado

At the meeting of the University of Colorado Branch on November 19, the speaker was Mr. C. M. Stannard, secretary of the Denver Gas and Electric Company, and past-president of the National Commercial Gas Association. His subject was "Commercial and Engineering Problems Confronting the Central Station." Mr. Stannard spoke particularly on the methods of training men for work on the commercial side of a central station company's activities.

### Colorado State College

A meeting of the Colorado State College Branch was held on November 28. The program consisted of a discussion of Mr. Irving Langmuir's recent Institute paper, *Tungsten Lamps of High Efficiency*. The paper was presented by Mr. L. M. Klinefelter, who had provided himself with several lamps illustrating some of the types discussed.

### Highland Park College

At the meeting of the Highland Park College Branch on November 14, Mr. Harry B. Wallin, of the Iowa Telephone Company, presented a paper describing the automatic ringing, two-party selective, "B" board trunking system, as used by that company. A large drawing had been prepared to show the circuits through the necessary eleven relays. Mr. Wallin exhibited a relay that was wound to 12,000 ohms resistance, and another that was a so-called "non-inductive" relay through which the voice currents must pass, and yet be capable of being magnetized.

### Iowa State College

At the meeting of the Iowa State College Branch on November 19, Mr. K. E. Kellenberger, superintendent of signals for the western division of the Northwestern Railroad, spoke on "Present-Day Practise in Electric Railway Signaling." The lecture was profusely illustrated with slides.

### University of Kansas

At the meeting of the University of Kansas Branch on October 22, Mr. Ross Parker, '12, now with the General Electric Company, read a paper on "Recent Developments by the General Electric Company." Professor Shaad then gave a talk explaining the plan and purpose of the student Branch of the A. I. E. E.

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At the meeting of the Branch on November 5, the speakers were Messrs. Brown, Fowler and Washburn, who described their work during the past summer in connection with the signal service of the Santa Fe Railroad.

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Professor Ray Jones was the speaker at the meeting on December 3. He gave a talk on problems confronting the Colorado Power Company of

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Boulder, Colo. A large number of slides was shown, illustrating the points discussed.

LAFAYETTE COLLEGE

The first meeting of the Lafayette College Branch for the season was held on October 22. Mr. G. P. Ellis, chairman of the Branch, and Professor Rood, gave talks explaining the purpose of the organization. Two papers on summer vacation work were then presented. Mr. R. K. Laros described the methods of making motor tests in the testing department of the General Electric Company at Lynn, and also described the student apprentice course conducted there. Mr. W. B. Killough described the manufacture and testing of special electric vehicle motors as carried on by the Diehl Company of Elizabethport, N. J.

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At the meeting of the Branch on October 29, Mr. J. M. Shimer read a paper on the new high-efficiency tungsten lamps and Mr. G. P. Ellis gave a paper on the homopolar generator, discussing its advantages and shortcomings. He cited several installations and showed how the limitations of this type of generator prevent its being widely used at present.

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At the next meeting, on November 5, Mr. H. J. Kerrick presented a paper on "The History of Arc Lamps," Mr. H. S. Conklin, Jr., one on "Types, Construction and Use of Fuses," and Mr. M. H. Simmons a paper on "Electric Mine Haulage."

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At the meeting on November 12, two papers were presented, "Electricity in the Beet Sugar Industry," by Mr. J. R. Clymer, and "Modes of Excitation of A-C. Generators" by Mr. E. E. Smith. Professor Rood also discussed the latter subject, pointing out the advisability of placing regulators on the feeders instead of on the machines.

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On November 19 three papers were presented, as follows: "The Electric Locomotive" by Mr. R. D. McManigal, "Electric Block Signals" by Mr. P. M. Lee, and "A New System of Power Development and Distribution for Easton, Pennsylvania," by Mr. V. A. Davison.

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Three papers were presented at the meeting on November 26. Mr. W. H. Howell spoke on "Competition in the Telephone Business." Mr. H. W. Bailey presented a paper on "Legislative Regulation of Wireless Telegraphy," and Mr. W. W. Thompson gave a paper on "Wireless Telephony," explaining the principles of the Preece ground system, the Collins aerial, and the Ruhmer photometric system.

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A special meeting of the Branch was held on December 2, when two papers were presented, "The Aluminum Electrolytic Rectifier" by Mr. H. C. Mitchell, and "Limiting Transmission Voltages" by Mr. F. L. Kolb.

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At the regular meeting on December 3, Mr. J. W. Magee read a paper on "The Choice of Frequency," Mr. L. C. Van Inwegen read a paper on "Operation of City Subways," comparing the systems in New York and Paris, and Mr. J. H. Kennedy spoke on "Electricity on the Farm."

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At the meeting of the Branch on December 10, Mr. LeRoy Lefferson gave a paper on "High-Tension Insulators." Professor Rood followed with a discussion on the protective grounding devices which have been used to protect insulators from lightning. "The Advantages of Motor Drive" was the title of an abstract by Mr. W. J. English, Jr., relating particularly to conditions found in machine shops. Mr. C. R. Lohman read a paper on "Faraday's Discoveries," and Mr. R. S. Soles concluded the program with "The Story of the Submarine Cable," describing the difficulties met with in the laying of the early transatlantic cables. Mr. Soles cited statistics showing that

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at the present time there are 34 companies, operating altogether 404 cables. A general discussion on cable laying followed.

### Lehigh University

A meeting of the Lehigh University Branch was held on October 23. Mr. J. S. Gemmel, '14, presented a paper on "Electrolytic Lightning Arresters," describing the construction features of this type and the method of installation and maintenance.. Mr. H. R. Lee, '06, superintendent of the Electrometallurgical Company's works at Holcomb Rock, Virginia, gave a short talk on "Some Aspects of Electrometallurgy."

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The next meeting of the Branch was held on November 13. The first speaker was Mr. G. Forster, '14, who read a paper on "Methods of Synchronizing." He discussed the principles underlying the practical use of an alternator as a synchronous motor, and the various means for determining the exact instant at which to throw the motor on the line.

The second speaker was Mr. H. H. Smith, chief of the research department of the Edison Storage Battery Company at Orange, N. J., who gave a short account of the development of the Edison nickel-iron storage cell. He described how the positive electrode is made of tubes of perforated steel ribbon and into these tubes finely-flaked nickel is pressed. The negative consists of hollow rectangular-shaped pockets also made of perforated ribbons of steel and filled with spongy metallic iron. The tubes and pockets are assembled into grids of various sizes, depending upon the capacity of battery required.

Mr. Smith showed various views of the cells and also of many severe tests to which they were subjected. He pointed out the advantages of lightness and ruggedness which this type of storage battery possesses over the lead cell, and said that although it is higher in first cost the years of service under rough conditions of all kinds make it the cheaper cell in the long run.

### University of Maine

The University of Maine Branch held an organization meeting on December 5, at which the following officers were elected: president, C. M. Kelley; vice president, P. B. Sheridan; secretary, E. L. Getchell; treasurer, Mark Pendleton. After discussing plans for the work of the year the meeting was adjourned.

### University of Michigan

The University of Michigan Branch held a meeting on October 23. Membership, program and publication committees were appointed, and it was resolved to meet every two weeks. Assistant-Professor A. H. Lovel presented a paper on "The Construction of a 110,000-volt Transmission Line." Professor Lovel gave a complete outline of the construction of the line, from the obtaining of the right-of-way to the actual charging of the line. He described novel methods of erecting towers in difficult locations and illustrated the points discussed with many lantern slides. The paper was discussed by Messrs. Rennie, Dutton, Erley and others.

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The next meeting of the Branch was held on November 13. Professor H. H. Higbie presented a paper on "Recent Developments in Electric Lighting."

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At the next meeting, on December 11, the speaker was Professor Sawyer of the Michigan Agricultural College, his subject being "Electricity on the Farm."

### University of Missouri

At the meeting of the University of Missouri Branch on October 13, Mr. P. W. Gumaer made an address on "The Action of the Mercury-Arc Rectifier as Explained by the Electron Theory." Mr. Gumaer first stated the theory that cathode rays are moving electric charges, and then showed by experiment that they travel in straight lines, and that these paths are deflected by a magnetic field. An electrostatic

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field will also deflect the rays. The electrostatic force acting on a particle depends only on the strength of the field and the amount of the charge, whereas the force produced by the magnet depends also on the velocity of the moving particle. By balancing the two effects and knowing the strength of the two fields the velocity can be calculated. This appears to range from 5000 to 50,000 miles per second.

A vapor in a perfectly dust-free space may be supersaturated without condensing, because some dust particle is needed for the vapor to condense on. If electrons are introduced into such a vapor, each electron appears to form the nucleus for the formation of a drop and a mist is formed. The drops then fall and their rate of falling shows their size, for the relation between the size, mass and rate of descent of small bodies in a gas medium is well established. The total condensation, divided by the amount of water in each drop, gives the number of drops. The total charge that is brought down is also measured, and with this and the number of charges known, the value of the individual charge may be calculated. The actual charge per electron figures out to be six divided by ten to the twenty-sixth power, electrostatic units.

Other experiments make it apparent that all matter is made up of positive and negative electrons. The molecule may be robbed of some of its negative electrons, and these may be set free in the surrounding space. A gas whose molecules have been so affected is said to be ionized, and the positive and negative charges in it are called ions. Such a gas is a fairly good conductor of electricity.

The explanation of the rectifier is based on the fact that mercury gives off ions at a temperature of about 300 deg. cent., whereas the carbon terminals give off no ions until heated up to a temperature of 1500 deg. cent. It is at the negative electrode that the heat is generated, little heat being produced at the positive terminal. Therefore if the mercury forms the negative terminal it is heated enough to give off ions and the vapor becomes a good conductor. If a carbon terminal becomes negative it does not become hot enough to give off ions, and therefore the surrounding vapor ceases to conduct.

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At the regular meeting of the Branch on October 27, the evening was devoted to a discussion of the subject of "Power Transmission." Mr. C. H. Kraft described the methods of line construction, and showed the general practise in regard to the choice of systems and voltages for various purposes. The talk was illustrated by a number of views of line towers, and some typical high-voltage insulators were shown.

Mr. J. H. Spurgeon dealt with the substations, and described the construction of some of the important parts of the apparatus, such as the oil switches and lightning arresters.

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The subject discussed at the meeting on November 10 was "Speed Control of Direct-Current Motors." Mr. T. B. Ellis treated the subject from the standpoint of series motors in street-car and railway service, comparing the power economy and effectiveness of the various plans. The principal means of control described were armature resistance, series-field shunts, change from series to multiple connections for motors and vice versa, and series and multiple connections of the field windings.

Mr. W. H. Kanzler discussed speed control as applied to shunt and compound variable-speed motors, first giving a summary of the uses of such motors. The methods of control described were armature resistance, field current adjustment, the use of separately controlled generators so as to vary the armature voltage, and the various systems involving the use of three or four wires giving different voltages.

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### Montana State College

The Montana State College Branch held a meeting on November 7. Mr. Max W. Kenck was elected chairman and Mr. J. A. Thaler secretary. Mr. Kenck gave a talk on the work of the Institute and the advantages to be derived from membership in the local Branch.

### University of Nebraska

The first meeting of the University of Nebraska Branch for the year was held on October 5. Committees were appointed and plans for the year discussed. The officers are Professor O. J. Ferguson, chairman; Professor V. L. Hollister, corresponding secretary; Mr. Gunther, recording secretary; and Mr. Edison, treasurer.

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The next meeting of the Branch was held on November 5. In view of the inability of the scheduled speaker to be present, a "round table" discussion was held, on questions brought up by the students. Professor O. J. Ferguson described the reactors inserted in sectionalized busbars and Professor V. L. Hollister made a few remarks on motor applications and costs.

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On December 2 the University of Nebraska Branch held a joint meeting with the local branch of the A.S.M.E. and the agricultural engineering students of the university. The meeting was addressed by Professor H. H. Norris, lately head of the electrical engineering department of Cornell University, on "Some Recent Developments in Electrical and Mechanical Engineering". Professor Norris spoke of the new developments in high-speed turbines of increased capacity, and new designs of synchronous converters. This address aroused great interest and elicited considerable discussion by both the faculty members and student members present.

### Ohio Northern University

The first meeting of the Ohio Northern University Branch for the current school year was held on October 15. Mr. G. A. Boesger gave a talk on "Operation of Frequency Changers" and on "Commutating-Pole Saturation in D-C. Machines". Mr. Harry Restofski then gave a talk on "Electrolysis", and was followed by Professor Thurston, who spoke on the benefit to be derived from student membership in the A.I.E.E.

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The second meeting of the Branch was held on October 29.

Mr. George F. Griffith gave a talk on "Advantages of the Steam Turbine". This talk led to a discussion of the relative merits of the steam turbine and the reciprocating engine.

Mr. G. H. Bull then spoke on "The Gas-Electric Railway Car", and pointed out the many conditions under which a gas-electric car can be operated with economy. The last talk was given by Mr. T. M. Freeman, on Dr. Langmuir's Institute paper, *Tungsten Lamps of High Efficiency*. Both of these talks were followed by general discussions.

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At the meeting of the Branch on November 17, Mr. J. H. Homrighous presented a paper on "2400-Volt Railway Electrification", and Mr. D. J. Goldberg spoke on "Practical Interior Wiring".

### Ohio State University

The Ohio State University Branch held its first meeting of the year on October 21. This took the form of a banquet at the Ohio Union, for the purpose of getting together and making the acquaintance of the juniors. The meeting was presided over by President Leo R. Yeager, and toasts were responded to by Professors Coddington, Flowers, and Caldwell.

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The next meeting of the Branch was held on November 19. It was decided to hold an "electrical show" in the spring of 1914, and a committee was appointed to make plans for it. Mr. John M. Strait presented a paper on "Railway Signaling", and Mr. Landis

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H. Brubaker a paper on "Telephone Transmission".

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At the meeting of the Branch on December 3, two papers were presented, "Copper Smelting" by Mr. William H. Noble, and "Practical Operation of the Standard Transformer", by Mr. J. E. Wilson.

OKLAHOMA AGRICULTURAL AND MECHANICAL COLLEGE

A meeting of the Oklahoma Agricultural and Mechanical College Branch was held on December 6, when the Institute paper, *Electric Power in the Construction of the Los Angeles Aqueduct*, by Mr. E. F. Scattergood, was discussed by Mr. Quentin Graham. Mr. R. A. Wood then gave a discussion of the Institute paper by Mr. W. L. R. Emmet, on *Proposed Applications of Electric Ship Propulsion.*

UNIVERSITY OF OKLAHOMA

The sixth regular meeting of the University of Oklahoma Branch was held on November 5. Professor H. B. Dwight made an address on the Institute and its student Branches, their organization and purpose. Mr. M. C. Oakes discussed the papers on *Tungsten Lamps of High Efficiency* presented by Messrs. Irving Langmuir and J. A. Orange at the Institute meeting at New York in October. Mr. D. E. Renshaw then made an address on the Mississippi River Power Company's development and plant at Keokuk, Iowa, illustrated from data gathered during a visit to the plant last March, and from bulletins issued previous to that time.

OREGON AGRICULTURAL COLLEGE

The opening meeting of the Oregon Agricultural College Branch was held on November 18, when Mr. A. O. Mangold was elected chairman and Mr. I. L. Olmsted secretary. An address on "Underwriting" was delivered by Mr. V. L. Vorse of the Underwriters Equitable Rating Bureau, of Portland, Ore.

UNIVERSITY OF OREGON

The University of Oregon Branch held a meeting on October 21. Professor R. H. Dearborn spoke on 'The Work of the Railroad Commission in Oregon", and Librarian M. H. Douglas spoke on "Indexing and Card Filing in Engineering Libraries".

PENNSYLVANIA STATE COLLEGE

The Pennsylvania State College Branch met on November 12, when Mr. A. D. Shultz read a paper on "History and Development of the Axle Generator System for Railway Car Lighting", and Mr. C. D. Gibbs read a paper on "The Application of Synchronous Motors for the Betterment of Service Standards".

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At the next meeting of the Branch, on December 10, a report was made by the committee which had been appointed by the Branch to confer with committees of the other engineering societies of the college on the advisability of establishing an engineering magazine. The report showed that sentiment was favorable and it was voted that the Branch support such a magazine if the project was initiated. Professor J. O. Kammerman then gave a talk on the value of apprenticeship courses for college graduates.

PURDUE UNIVERSITY

The Purdue University Branch held its opening meeting of the year on October 7, which was largely devoted to getting acquainted with and welcoming new comers.

Chairman Smith opened the meeting with a brief history of the organization and its affiliation with the Institute. He called attention to the fact that the Branch has a reading room at the disposal of its members which is supplied with several leading engineering periodicals, Institute PROCEEDINGS and catalogues. Dean Benjamin and Professors Harding and Ewing discussed the value of A. I. E. E. membership to students.

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The second meeting of the Branch, on October 15, was addressed by Mr. B. P. Miessner, '17, who spoke on "The Wireless Control of Torpedoes".

For the past two years Mr. Miessner has been connected with research work in the vicinity of Boston and has been associated with Mr. Hammond, an expert in wireless telegraphy. Mr. Miessner first told of the operation and construction of the ordinary Whitehead torpedo and of its great disadvantage, viz., the fact that it cannot be controlled after it is once fired, on account of which the percentage of hits with it is not very large, since there are numerous variables such as the tide and waves which tend to carry it from its intended course.

Mr. Miessner then spoke of the dirigible torpedo. It is a semi-submarine and is controlled through an inland station which in turn is controlled by turrets along the coast. Any one of these turrets will control the central station. Along the coast there is also a torpedo bed containing several of the missiles. Each of these torpedoes has a different characteristic wave by means of which it is controlled, and the operator's control of them is far more accurate than in the case of the Whitehead. The dirigible is built like a submarine boat, with the charge of explosive in the head, the machinery in the center, and the control and rudder at the rear end. The ordinary torpedo is lost after firing if it does not hit its mark, but the dirigible can be recalled and used again. The speed of the dirigible is about forty miles per hour, and since a very small part is above the water, it serves as a very poor target for the enemy.

### Rhode Island State College

The first regular meeting of the Rhode Island State College Branch for the season was held on November 12. Professor L. P. Dickinson gave a short talk about the recent developments in tungsten lamps. He brought up especially the experiments that have been performed with the nitrogen-filled bulbs.

### Rose Polytechnic Institute

On October 15 the Rose Polytechnic Institute Branch held a meeting and organized for the ensuing year. The officers elected were Charles F. Harris, chairman, and Claude A. Lyon, secretary.

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The second meeting of the Branch was held on October 16. The object of the meeting was to demonstrate the X-ray tube, the taking of X-ray photographs, and the effect of high voltage through air and vacuum.

Professor C. C. Knipmeyer demonstrated the X-ray machine, and corona loss in a high-tension transmission line, by the use of a Tesla coil, made at the Institute, using condensers producing a voltage of 900,000 volts; but on account of magnetic leakage only 400,000 volts could be actually used.

An interesting feature of the corona effect shown was the producing of the words "Rose Polytechnic" on a prepared shield at the end of the room approximately twenty feet from the electrical discharge.

Several X-ray photographs were taken of different students, some of them showing bone fractures. The plates were developed by Professors Peddle and Wischmeyer and displayed.

Doctor Johonnott discussed and demonstrated high voltages through air and vacuum, and also explained how the spark is made. Different insulators were caused to fail from the effect of high voltage.

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The third meeting of the Rose Polytechnic Branch was held on November 6, as a joint meeting with the Camera Club, Professor Peddle being the faculty advisor of that club.

Professor Peddle lectured and showed some interesting slides of color photography, after which more X-ray photographs were taken and discussed.

### Stanford University

At the regular meeting of the Stanford University Branch held on October

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16, Professor D. Folsom of the mining department gave a paper on "Electricity in Mines and Mining." He pointed out the especially hard points which must be overcome before a general adoption of electricity is made. Its applications to all phases of both underground and surface conditions were taken up and the merits and deficiencies discussed.

A new organization has been effected whereby the entire engineering student body may gather on certain evenings to hear talks by prominent engineers who are resident on or are visiting the Pacific Coast.

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The Mechanical and Electrical Engineering Societies held an informal joint smoker at the Faculty Club House on the evening of October 28. This was the first engineering smoker of this kind that has been held at Stanford and was given in an endeavor to have the underclass men of both courses meet the upper class men and faculty in an informal way and to further the spirit of personal acquaintanceship with all members of the university, especially the faculty.

Professor W. F. Durand of the mechanical engineering department gave the address of welcome to the freshmen. Professor H. J. Ryan of the electrical engineering department gave an interesting talk describing the formation and growth of the first engineering societies at Cornell University. Mr. G. M. Brill, a consulting engineer of Chicago and a past vice-president of the A.S.M.E., also made a short speech on the necessary qualities for a successful engineer.

The attendance was very representative of the various classes, there being about 135 people present.

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The Branch listened to a talk on the morning of Nov. 13, by Mr. H. M. Alvord of the General Electric Company, on the organization, growth, and development of that company. By the aid of lantern slides he was able to present his subject in an interesting manner.

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On November 20, Mr. O'Shaughnessy, City Engineer of San Francisco, gave a talk to the engineering societies on the Hetch Hetchy water supply project of San Francisco. Lantern slides were used and helped to bring out very clearly the enormous engineering difficulties of the project, as well as the legal questions that must be settled before the project can be completed.

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The Branch held two meetings on December 4. The afternoon meeting was in the nature of a University Engineering Assembly and was addressed by Mr. Allen H. Babcock, chief electrical engineer of the Harriman Lines. Mr. Babcock went over his paper that was presented at the Vancouver Convention in great detail, explaining every item in the paper, both from an engineering and financial standpoint.

The evening meeting listened to a talk by Mr. E. O. Shreve, of the General Electric Company. Mr. Shreve spoke on "Steam Turbines, Their Uses and Development." Through his courtesy the Branch has been extended an invitation to visit the new naval collier *Jupiter* before the official acceptance trials are conducted.

### Syracuse University

A meeting of the Syracuse University Branch was held on December 1, when Mr. R. M. Brockway presented an abstract of the Institute paper by Dr. Langmuir on *Tungsten Lamps of High Efficiency.*

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At the meeting of the Branch on December 15, Mr. Stuart M. Cooper, 1914, presented a paper on "The Grounded Neutral".

### Agricultural and Mechanical College of Texas

The Agricultural and Mechanical College of Texas Branch held a meeting on October 23, when Professor F. C.

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Bolton gave an illustrated talk on scenes in and around the Westinghouse Company's plant, and Mr. O. B. Wooten gave an outline of the apprentice course system of that company.

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At the next meeting of the Branch on November 7, two papers were presented, "Interpoles for Motors and Generators" by Mr. Nash, and "Methods of Charging for Power", by Mr. H. K. Baker.

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At the meeting on November 14 Dr. Scott, consulting engineer, of Dallas, Texas, made an address on "Power Plant Economy". Dr. Scott discussed the recent devices for improvement of power plant economy and their advantages and disadvantages. Mr. Kenyon then made a brief talk, outlining the apprentice course offered to college graduates by the General Electric Company.

THROOP COLLEGE OF TECHNOLOGY

Mr. Eric Kobbe, assistant electrical engineer of the Pasadena office of the Home Telephone and Telegraph Company, made an address at the meeting of the Throop College of Technology Branch, on October 24, on "The History of Telephone Development".

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The next meeting of the Branch was held on November 22, when Messrs. Elliott, Holms and Bultman, of the class of 1915, and Mr. Claude Sopp, of the class of 1917, gave an account of their summer experience with the Stone and Webster Construction Company during the construction of the 150,000-volt substation of the Big Creek system of the Pacific Light and Power Company.

WASHINGTON UNIVERSITY

The Washington University Branch held a meeting on October 16, when officers were elected for the year, as follows: chairman, R. Duncan; vice-chairman, Mr. Niemiller; and secretary-treasurer, C. C. Hardy. Professor Langsdorf then made an address on the importance of the organization to the student members.

The next meeting of the Washington University Branch was held on October 23. The chairman reported on the joint meeting of engineering societies of the University to be held to consider the proposed engineering council, and he was given power to appoint a member to act with him as a committee of the Branch at this joint meeting.

UNIVERSITY OF WASHINGTON

The opening meeting of the fall term of the University of Washington Branch was held on October 7. Professor C. E. Magnusson made an address dealing with electrical engineering as a vocation. He told of the problems which confronted him when he entered as a freshman at the University of Minnesota, and gave the reasons which determined him to choose the electrical profession.

Mr. A. A. Miller supplemented the lecture with his experiences in choosing a vocation on entering the University of Nebraska.

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The next meeting of the Branch was held on November 4. The paper of the evening, read by Professor E. A. Loew, was entitled "The Historical Background of Electrical Engineering". The paper showed that there were two distinct periods in the discovery of magnetism and electricity. The first period was one of mystery and superstition, and the second, one of scientific investigation. The work on magnetism and electricity was carried out as though those subjects were in no way interrelated. With Oersted's discovery came the awakening to the fact that they were closely related. The author then dealt, in some detail, with the work of Faraday, giving his life history and the work he did leading up to the discovery of the fundamental laws of electricity and magnetism.

WORCESTER POLYTECHNIC INSTITUTE

The annual "ladies' night" lecture of the Worcester Polytechnic Institute Branch was held on November 14. Professor H. B. Smith, director of the

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department of electrical engineering, speaking on "Two Months in India", entertained a crowd of three hundred for an hour and three-quarters with slides made from photographs taken during a recent trip. He showed also some of the oddly woven and colored cloths, with hats, shoes, and knives used by the natives, illustrating the manner in which they drape their garments.

The meeting was later adjourned to the general laboratory, where refreshments were served, followed by dancing in the gallery.

## Personal

MR. PHILIP E. HART has accepted an appointment as resident engineer of the Dorada Railway Ropeway Extension, Honda, Colombia, South America. Mr. Hart has been until recently located in Montreal, Que.

MR. HENRY H. NORRIS is making a tour of colleges and electrical installations in Illinois, Missouri, Nebraska, Kansas and neighboring states, engaged in a study of matters of technical interest. Mr. Norris is now associate editor of the *Electrical World* and the *Electric Railway Journal*.

MR. PAUL A. WESTBURG has become president and treasurer of the Badt-Westburg Electric Company, Chicago representatives for the Weston Electrical Instrument Company and the Ward Leonard Electric Company. The offices of the company have been removed from 1504 Monadnock Block to 832 Monadnock Block, Chicago, to provide larger quarters for their increasing business.

MR. THEODORE A. BERGEN, who for a number of years has been connected with Lockwood, Greene and Company, architects and engineers, latterly as head of the firm's mechanical and electrical department in Chicago, has associated himself with The Combined Industries of Sweden (Sveriges Industriforbund), and will manage their engineering department in Stockholm, beginning early in the year.

MR. J. G. WHITE recently returned to New York after six months' absence in England and on the Continent. Much of his time was spent in London at the home office of J. G. White and Company, Limited, of which he is president. One of the important recent financial undertakings of the firm is the formation of the International Light and Power Company, Limited, a holding company owning securities of several electric light and tramway properties throughout South America.

MR. ETIENNE DE FODOR, Director-General of the Budapest General Electric Company, gave an illustrated lecture on the "Electrification of Trunk Lines" on December 5, 1913, in the rooms of the Pest Lloyd Society, and in the presence of an unusually brilliant audience. Among his listeners were Archduke Joseph Franz of Austria with his suite, Baron Adolf Kohner, president of the Lloyd Society in Pest, several secretaries of state of Hungary, the director of Hungarian state railways, Sigmund v. Kotanyi, and many prominent members of both houses of Parliament, as well as representatives of the industries and schools.

The speaker was thoroughly in favor of an extension of electrification to the Hungarian railway system. The electric railways built in Europe during recent years (referring to trunk lines only) have proved a financial success. An electric line is cheaper than a steam road to build, because it allows the use of steeper grades; and it is cheaper to operate. The latter is not so obvious at first sight, because one is inclined to believe that it ought to be simpler and cheaper to haul coal one way, with the locomotive, than first to take it to the electric plant, and then convey the current all over the country, with all the attending losses. A boiler on the loco-

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motive appears also to be a simpler and more economical arrangement than the complicated system of the generating station, with its boilers and electrical machinery, the transmission system overland, and the motors on the locomotives. As a matter of fact, however, coal has to be hauled several ways before it is consumed in the locomotive furnace: first from the mine to the coal depot on the road (and the speaker surprised his hearers by showing them what large areas of valuable space were occupied by such depots in Budapest), an operation which for the Hungarian railroads involves an expense of 15,000,000 krones per year. Then the coal has to be loaded on the tender of the locomotive, and carried again as dead weight at no inconsiderable cost, while a further source of expense is the taking care of the ashes and slag. Should the railroads be electrified, the generating stations might be placed right at the mouths of the mines, the coal being delivered from underground straight to the boiler, without any unnecessary handling, the distribution of coal producing regions in Hungary being such as to permit providing each section of the country with all the power it needs for its trunk lines.

A further advantage of electrification for Hungary lies in the fact that at present a considerable part of the railroad demand for coal has to be supplied from abroad, since only good coal can be burned on locomotives, and such coal is scarce in the country. In central generating stations, however, poor coal, such as lignite, can be handled quite successfully, as has been shown both by German and Austrian practise, and the importation of foreign coals could therefore be discontinued. The maintenance expenses of an electric line are also more attractive than those of steam lines, since the heavy item of constant repairs to the locomotive boilers (due to their overstraining) is eliminated. There are as yet no electrically operated trunk lines in Hungary, the proposed electrification of some lines being held up for military reasons, but the speaker strongly advocated the necessity of paying far more attention to this problem than it has received hitherto.

At the conclusion of his lecture Mr. de Fodor was warmly thanked by the President of the Lloyd Society and Archduke Joseph Franz of Austria.

## Obituary

CLARENCE E. DELAFIELD, Assoc. A. I. E. E., district manager of the Intermountain territory of the Crocker-Wheeler Company, died on November 30, 1913, in Denver, Colorado. Mr. Delafield was associated for a number of years with the Wagner Electric Manufacturing Company of St. Louis, Mo., and was later sales manager of the Ohio Brass Company of Mansfield, O. He entered the service of the Crocker-Wheeler Company on September 1, 1909, and had recently filled the position of district manager of that company's Intermountain territory, with headquarters at Denver and Salt Lake City. He was elected an Associate of the Institute on April 5, 1912.

## Abstracts of Proceedings of Foreign Engineering Societies

### SOCIÉTÉ INTERNATIONALE DES ELECTRICIENS
### MEETING OF DECEMBER 3, 1913

"Electric Traction—New system of self-regulation. Starting without resistance and recuperation." By R. Legouez.

The present system is a rational solution of the problem of regulation of traction motors with series excitation: it is entirely automatic, permits the elimination of starting resistances and the recuperation of energy.

An automatic starting may be obtained by using in a system of step-up-step-down transformers, a constant-current machine; the application of this idea to traction and the use of stabilizing devices permitting recupera-

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tion either while braking or on inclines, are essential characteristics of this system.

The stabilizing feature consists essentially of the production of a sufficient damping in the primary circuit of the traction motor, so that all instantaneous variations of the main current shall be without effect on the excitation of the motors.

The first train of multiple units equipped with this system and delivered to the Metropolitan Railway in Paris has just been tested. These tests have fully confirmed the correctness of the theoretic deductions, and, in particular, have shown the very important economy in power that this system makes possible.

## Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgement.

Accident Prevention. Safety First. Philadelphia, United Gas Improvement Co., 1913. (Purchase.)

American Institute of Electrical Engineers. Index to Transactions, vol. 1, 1884-1900. New York, 1913.

Association of Iron and Steel Electrical Engineers. Proceedings of 2d Annual Convention, Buffalo, N. Y., June 23-26, 1909.

——Proceedings of Pittsburgh, Oct. 20-22, 1909.

——Minutes and Papers. 4th Annual Convention. Oct. 17-20, 1910.

——Standard Crane Specifications. 4th Annual Convention. Oct. 17-20, 1910.

——Proceedings of 5th Annual Convention, Sep 25-29, 1911; 6th Annual Convention, Sept. 30, Oct. 1-5, 1912.

——Constitution and By-laws. amended Nov. 1, 1911.

Der Aufzugbau. Ein Handbuch für das Konstruktionsbureau. By Hugo Bethimann. Braunschweig, 1913. (Gift of Weaver Fund.)

British Association for the Advancement of Science. Reports of the Committee on Electrical Standards. Cambridge, 1913. (Purchase.)

Canadian Electrical Association. Proceedings of 23rd Annual Convention, 1913. Toronto, 1913. (Exchange.)

Carnegie Library of Pittsburgh. Classified Catalogue 1907-1911--part V—Literature. Pittsburgh, 1913. (Exchange.)

Commission Regulation of Public Utilities. A compilation and analysis of laws of forty-three states and of the Federal government for the regulation by central commissions of railroads and other public utilities. New York, 1913. (Purchase.)

Conduction of Electricity through Gases. Ed. 2. By J. J. Thomson. Cambridge, 1906. (Purchase.)

Delaware College. Catalogue of the Officers and Students, 1912-13. Newark, 1913. (Gift of Delaware College.)

Electrical Engineering. By C. V. Christie. New York, McGraw-Hill Book Co., 1913. (Purchase.)

Elektrische Strassenbahen und strassenbahnähnliche Vorort und Uberlandbahnen. By Karl Trautvetter. Berlin, 1913. (Purchase.)

First Coöperative Safety Congress. Proceedings, held under the auspices of Association of Iron and Steel Electrical Engineers. Milwaukee, Sept. 30-Oct. 5, 1912. (Gift of Association of Iron and Steel Electrical Engineers.)

International Catalogue of Scientific Literature. 11th Annual Issue. B—Mechanics. London, 1913. (Gift of E. D. Adams.)

International Radiotelegraph Convention, London, 1912. Resolutions, rules, etc.

——International Morse Code and Conventional signals.

——List of Abbreviations to be used in Radio communication.

——Regulations for Radio Apparatus and Operators on Steamers, edition July 1, 1913.

——Regulations governing radio communication, edition July 1, 1913. (Gift of U. S. Bureau of Navigation, Dept. of Commerce.)

National Board of Fire Underwriters. List of Electrical Fittings. October, 1903. N.p. 1913. (Gift of Underwriters Laboratories.) Inc.)

National Conservation Congress (4th) Proceedings, Oct. 1-4, 1912. Indianapolis, 1912. (Gift of F. L. Hutchinson.)

——(5th) Committee on Water Power, unanimous recommendations. Nov. 18-20, 1913.

——(5th) Report of the Committee on Water Power, Nov. 18-20, 1913.

——(5th) Report of the Minority on Water Power National Electric Light Association. 36th Convention. Papers, Reports and Discussions 4 vols. Chicago, 1913. (Exchange.)

National Electric Light Association. New England Section. Proceedings of Annual Convention. 4th, 1912. (Gift of Boston Section, of N. E. L. A.)

Normalien, Vorschriften und Leitsätze des Verbandes Deutscher Elektrotechniker. Ed. 8. By Georg Dettmar. Berlin, 1913. (Purchase.)

Radioactive Substances and their radiations. By E. Rutherford. Cambridge, 1913. (Purchase.)

Wood-using Industries of Florida. By Hu Maxwell. Tallahassee, 1913. (Gift of U. S. Department of Agriculture.)

Wood-using Industries of Iowa. Ames, 1913. (Gift of U. S. Department of Agriculture.)

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# INSTITUTE REPRESENTATIVES

(Continued.)

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| **Boston**.....Feb. 13, '03 | N. J. Neall | Leavitt L. Edgar, 39 Boylston St., Boston, Mass. |
| **Chicago**.....1893 | D. W. Roper. | E. W. Allen, 1028 Monadnock Building, Chicago, Ill. |
| **Cleveland**.....Sept. 27, '07 | J. C. Lincoln. | R. E. Scovel, 1663 East 86th Street, Cleveland, Ohio. |
| **Detroit Ann Arbor**.Jan. 13, '11 | A. R. Sawyer. | Ray K. Holland, Cornwall Building, Ann Arbor, Mich. |
| **Fort Wayne**.....Aug. 14, '08 | T. W. Behan. | P. H. Haselton, Fort Wayne Electric Works. Ft. Wayne, Ind. |
| **Indianapolis-Lafayette**. Jan. 12, '12 | O. S. More. | G. B. Schley, 805 Pythian Building, Indianapolis, Ind. |
| **Ithaca**.....Oct. 15, '02 | E. L. Nichols. | George S. Macomber, Cornell University, Ithaca, N. Y. |
| **Los Angeles**.....May 19, '08 | E. R. Northmore. | C. G. Pyle, 914 Hibernian Bldg., Los Angeles, Cal. |
| **Lynn**.....Aug. 22, '11 | E. R. Berry. | J. A. McManus, Jr., General Electric Co., Lynn, Mass. |
| **Madison**.....Jan. 8, '09 | Edward Bennett. | F. A. Kartak, Univ. of Wisconsin, Madison, Wis. |
| **Mexico**.....Dec. 13, '07 | Norman Rowe. | James Carson, Mexican Light and Power Company, Mexico City, Mexico. |
| **Milwaukee**.....Feb. 11, '10 | L. E. Bogen. | A. J. Goedgen, Milwaukee Electric Ry. and Lt. Co., Milwaukee, Wis. |
| **Minnesota**.....Apr. 7, '02 | W. T. Ryan. | Fred G. Dustin, 9 South Fifth St., Minneapolis, Minn. |
| **Panama**.....Oct. 10, '13 | Edward Schildhauer. | W. H. Rose, Gatun, Canal Zone. |
| **Philadelphia**.....Feb. 18, '03 | A. R. Cheyney. | H. F. Sanville, 1326 Chestnut St., Philadelphia, Pa. |
| **Pittsburgh**.....Oct. 13, '02 | A. M. Dudley. | E. R. Spencer, 814 Frick Building, Pittsburgh, Pa. |
| **Pittsfield**.....Mar. 25, '04 | J. J. Frank. | G. W. Wade, General Electric Company, Pittsfield, Mass. |
| **Portland, Ore**.....May 18, '09 | G. P. Nock, | R. F. Monges, G. E. Co., Electric Building, Portland, Ore. |
| **San Francisco**.....Dec. 23, '04 | A. H. Griswold. | A. G. Jones, 819 Rialto Building, San Francisco, Cal. |
| **Schenectady**.....Jan. 26, '03 | George H. Hill. | John R. Hewett, Gen. Elec. Co., Schenectady, N. Y. |
| **Seattle**.....Jan. 19, '04 | S. C. Lindsay. | E. A. Loew, University of Washington, Seattle, Wash. |
| **St. Louis**.....Jan. 14, '03 | F. J. Bullivant. | A. McR. Harrelson, Emerson Electric Mfg. Co., St. Louis, Mo. |
| **Spokane**.....Feb. 14, '13 | J. B. Fisken. | H. B. Peirce, Box 1436, Spokane, Wash. |
| **Toledo**.....June 3, '07 | George E. Kirk, | Max Neuber, Care of Cohen, Freidlander & Martin, |
| **Toronto**.....Sept. 30, '03 | D. H. McDougall. | H. T. Case. Toledo, O. Continental Life Bldg., Toronto, Ont. |
| **Urbana**.....Nov. 25, '02 | Morgan Brooks. | I. W. Fisk, University of Illinois, Urbana, Ill. |
| **Vancouver**.....Aug. 22, '11 | E. M. Breed, | L. G. Robinson, 1003 Holden Building, Vancouver, B. C. |
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| Arkansas, Univ. of.....Mar. 25, '04 | S. S. McGill. | M. B. Roys, Univ. of Arkansas, Fayetteville, Ark. |
| Armour Institute.....Feb. 26, '04 | E. L. Nelson. | T. C. Bolton, Armour Inst. Tech., Chicago, Ill. |
| Bucknell University.....May 17, '10 | F. O. Schnure. | J. M. Hillman, Bucknell University, Lewisburg, Pa. |
| California Univ. of.....Feb. 9, '12 | Charles Z. Yost. | L. E. Rushton, University of California, Berkeley, Cal. |
| Cincinnati, Univ. of.....Apr. 10, '08 | John H. Stewart. | J. S. Bishop, 2345 Kemper Lane, Cincinnati, Ohio. |
| Clemson Agricultural College.....Nov. 8, '12 | F. J. Jervey. | F. H. McDonald, Clemson College, S. C. |
| Colorado State Agricultural College.....Feb. 11, '10 | Robert O. Sewell. | R. K. Havighorst, Colorado State Agricultural College, Fort Collins, Colo. |
| Colorado, Univ. of.....Dec. 16, '04 | L. E. Sweitzer. | Frank A. Redding, University of Colorado, Boulder, Colo. |
| Highland Park College..Oct. 11, '12 | E. B. Williams. | Ralph R. Chatterton, Highland Park College, Des Moines, Iowa. |
| Iowa State College.....Apr. 15, '03 | Earle G. Nichols. | F. A. Robbins, Iowa State College, Ames, Iowa. |
| Iowa, Univ. of.....May 18, '09 | J. H. Scanlon. | A. H. Ford, University of Iowa, Iowa City, Ia. |
| Kansas State Agr. Col....Jan. 10, '08 | C. A. Leech. | W. C. Lane, Kansas State Agric. Col., Manhattan, Kan. |
| Kansas, Univ of.....Mar. 18, '08 | H. C. Hansen. | L. M. Bocker, Univ. of Kansas, Lawrence, Kan. |
| Kentucky, State Univ. of. Oct. 14, '10 | H. B. Hedges. | H. Tyler Watts, 315 East Maxwell Street Lexington, Ky |
| Lafayette College.....Apr. 5, '12 | G. P. Ellis. | V. A. Davison, Lafayette College, Easton, Pa. |
| Lehigh University.....Oct. 15, '02 | W. B. Todd. | G. Forster, Lehigh University, S. Bethlehem, Pa. |
| Lewis Institute.....Nov. 8, '07 | Ralph Kilner. | A. H. Fensholt, Lewis Institute, Chicago, Ill. |
| Maine, Univ of.....Dec. 26, '06 | Howard O.Burgess | J. Larcom Ober, S. A. E. House, Orono, Maine. |
| Michigan Univ of.....Mar. 25, '04 | P. H. Evans. | W. B. Kopfer, 616 Church Street, Ann Arbor, Mich. |
| Missouri, Univ of.....Jan. 10, '03 | H. B. Shaw. | E. W. Kellogg, 9 Engineering Building, Columbia, Mo. |
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| North Carolina Col. of Agr. and Mech. Arts.....Feb. 11, '10 | Wm. H. Browne, Jr. | James Fontaine, West Raleigh, N. C. |
| Ohio Northern Univ.....Feb. 9, '12 | George E. Boesger | Harry Restofski, Ohio Northern University, Ada, Ohio. |
| Ohio State Univ.....Dec. 20, '02 | L. R. Yeager. | John M. Strait, Ohio State Univ., Columbus, Ohio. |
| Oklahoma Agricultural and Mech. Coll.....Oct. 13, '11 | A. P. Little, | Quentin Graham, 416 Hester Street, Stillwater, Okla. |
| Oklahoma, Univ of.....Oct. 11, '12 | R. D. Evans. | L. J. Hibbard, Univ. of Oklahoma, Norman, Okla. |
| Oregon Agr. Col.....Mar. 24, '08 | A. O. Mangold. | I. L. Olmsted, Oregon Agric. Col., Corvallis, Ore. |
| Oregon, Univ. of.....Nov. 11, '10 | C. R. Reid, | C. H. Van Duyn, Univ. of Oregon, Eugene, Oregon. |
| Penn State College.....Dec. 20, '02 | T. A. Jones. | A. D. Shultz, State College, Pa. |
| Purdue Univ.....Jan. 26, '03 | C. F. Harding. | A. N. Topping, Purdue University, Lafayette, Ind. |
| Rensselaer Poly. Inst....Nov. 12, '09 | E. D. N. Schulte. | W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y. |
| Rose Polytechnic Inst....Nov. 10, '11 | Charles F. Harris. | Claude A. Lyon, 1331 Liberty Avenue, Terre Haute, Ind. |
| Rhode Island State Coll..Mar. 14, '13 | Harry Webb. | P. M. Randall, Rhode Island State College, Kingston, R. I. |
| Stanford Univ.....Dec. 13, '07 | G. O. Wilson. | L. M. Bussert, Stanford University, Cal. |
| Syracuse Univ.....Feb. 24, '05 | W. P. Graham. | R. A. Porter, Syracuse University, Syracuse, N. Y. |
| Texas, Univ. of.....Feb. 14, '08 | J. A. Correll. | Joseph W. Ramsey, University of Texas, Austin, Tex. |
| Throop College of Technology.....Oct. 14, '10 | Ray Gerhart. | R. W. Parkinson, Throop Poly. Institute, Pasadena, Cal. |
| Univ. of Washington.....Dec. 13, '12 | A. P. Newbury. | Charles A. Stanwick, Univ. of Washington, Seattle, Wash. |
| Vermont, Univ. of.....Nov. 11, '10 | Walter L. Upson. | O. Krupp, 65 North Bend St., Burlington, Vt. |
| Virginia, Univ. of.....Feb. 9, '12 | Walter S. Rodman | Henry Woodman Clark, A. X. P. House, University, Virginia. |
| Wash., State Coll of.....Dec. 13, '07 | M. K. Akers. | H. V. Carpenter, State Col of Wash., Pullman, Wash. |
| Washington Univ.....Feb. 26, '04 | R. D. Duncan, Jr. | C. C. Hardy, Washington University, St. Louis, Mo. |
| Worcester Poly. Inst.....Mar. 25, '04 | W. C. Blanchard. | Harry B. Lindsay, Worcester Poly. Inst., Worcester, Mass. |
| Yale University.....Oct. 13, '11 | R. G. Warner. | K. B. Jones, 136 Vanderbilt-Scientific, New Haven, Conn. |

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SECTION II

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of the

# American Institute

of

# Electrical Engineers

Papers, Discussions and Reports

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**PROCEEDINGS**

OF THE

**American Institute**

OF

**Electrical Engineers.**

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Vol. XXXIII **February, 1914** No. 2

## A. I. E. E. Midwinter Convention

The Second Annual Midwinter Convention of the A. I. E. E. will be held in the Engineering Societies Building, New York, February 25th to 27th, 1914.

The Convention will be under the auspices of the Electric Power Committee, and each of the six technical sessions at the convention will be devoted to one of the sub-committees into which the Electric Power Committee is divided.

The registration headquarters of the Institute during the convention will be in the lobby of the Engineering Societies Building and members and guests are requested to register there on their arrival at the building.

As ample hotel accommodations are available in the neighborhood of Insitute headquarters, no special hotel arrangements have been made; also no special transportation rates are available.

The complete list of papers and reports to be presented at the convention is given in the following program:

### PROGRAM

Reprints of the papers to be presented at the Convention will be available without charge and will be distributed at registration headquarters. All of the papers except Nos. 1, 12, 14 and 15, are printed in this issue of the PROCEEDINGS.

### Wednesday, February 25

10:00 A. M.

OPENING SESSION

The Convention will open Wednesday morning with an introductory address by President C. O. Mailloux, after which the following papers and reports will be presented.

1. Electric Power, by D. B. Rushmore and E. A. Lof.
2. Sub-Committee Report—*Scope of the Engineering Data Sub-Committee*, P. H. Thomas, Chairman.
3. Sub-Committee Report—*The Feasibility of an A. I. E. E. Handbook*, Harold Pender, Chairman.

2:00 P. M.

POWER STATION SESSION

4. *Protective Reactances in Large Power Stations*, by James Lyman, Allen M. Rossman, and Leslie L. Perry.
5. *Outdoor versus Indoor Substations*, by Alexander Macomber.
6. *Indoor and Outdoor Substations in Pennsylvania*, by H. L. Fullerton.
7. *Outdoor Substations in New England*, by Fred L. Hunt.
8. *Outdoor Substations in the Middle West*, by Leslie L. Perry.
9. Suggestions for Discussio non Electrical Features of Power Station Design, by A. H. Kruesi.

7:30 P. M.

Organization dinner, International Electrical Congress. See the notice which follows this program.

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**Thursday, February 26**

10:00 A. M.

TRANSMISSION SESSION

10. Sub-Committee Report—*Problems of High-Tension Transmission Lines*—with four appendixes—P. W. Sothman, Chairman.
    Appendix 1. *Deterioration of Porcelain Insulators in Service*, by J. A. Brundige.
    Appendix 2. *Radius of Influence of a Direct Lighting Stroke*, by L. C. Nicholson.
    Appendix 3. *Transmission Line Problems in the West*, by P. M. Downing.
    Appendix 4. *Switching*, by G. Faccioli.
11. *Practical Operation of Suspension Insulators*, by H. W. Buck.

2:00 P. M.

POWER GENERATION SESSION

12. *The Economical Capacity of a Combined Hydroelectric and Steam Power Plant*, by C. T. Hutchinson.

8:30 P.M.

Meeting on International Electrical Congress, San Francisco, 1915, under the auspices of the Committee on Organization of International Electrical Congress.

**Friday, February 27**

10:00 A.M.

DISTRIBUTION SESSION

13. Sub-Committee Report—*Distribution of Electrical Energy*—with nine appendixes—P. Junkersfeld, Chairman.
    Appendix 1. *Three-Wire D-C. Distribution*, by Philip Torchio.
    Appendix 2. *Alternating - Current Distribution*, by H. B. Gear.
    Appendix 3. *Effect of Consumers' Apparatus and Wiring on Distribution*, by H. Goodwin.
    Appendix 4. *Direct-Current Distribution for Surface Railways,—Urban Service*, by R. H. Rice.
    Appendix 5. *Direct-Current Distribution for Underground and Elevated Railways*, by E. J. Blair.
    Appendix 6. *Direct-Current Distribution for Interurban and Steam Railroads*, by W. G. Carlton.
    Appendix 7. *Alternating-Current Distribution for Interurban and Steam Railroads*, by W. S. Murray.
    Appendix 8. *The Relations of Distribution Problems and Switching Equipment*, by E. B. Merriam.
    Appendix 9. *Distribution for Street Lighting Service*, by P.M. Lincoln.

2:00 P.M.

PROTECTIVE APPARATUS SESSION

14. *Recording Devices*, by C. P. Steinmetz.
15. *High-Frequency Relays*, by E. E. F. Creighton.

8:00 P.M.

Informal reception and entertainment, details of which will be announced later.

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## Organization Dinner, International Electrical Congress

On Wednesday evening, February 25, during the midwinter convention of the American Institute of Electrical Engineers, the organization dinner of the International Electrical Congress will be held at the Engineers' Club, West Fortieth Street, New York City. Plans will be discussed for the congress, which is to be convened at San Francisco in September, 1915, during the Panama-Pacific Exposition. At the time of the dinner, an opportunity will also be given for the executive committee to report its progress on arrangements to the general Congress Committee, and a world-wide campaign for members will be launched. Invitations to be present at the organization dinner will be issued to members of the Congress Committee, to members of committees of the American Institute of Electrical Engineers, and to officers of the Institute and its Sections.

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## Special Trains to International Electrical Congress, San Francisco, 1915

Plans are already well under way for one or more special trains from the East to San Francisco in connection with the International Electrical Congress to be held in that city in September, 1915. The trains themselves will represent the last word in safety and comfort, while their itineraries will be laid out to include the finest scenery in the country.

The tentative program, which at a later date will be submitted in detail to the engineers of the United States and other countries for an expression of their individual preferences, includes a round trip of about 30 days' duration, with stops in Chicago, Colorado Springs, Salt Lake City, San Francisco, Santa Barbara and Los Angeles. At each one of these places, special arrangements will be made by local committees for the comfort and entertainment of the members of the party.

Other features of the trip will be the Royal Gorge, the Feather River Canyon, and a four-day visit to the Yellowstone National Park on the way out, with a 24-hour stop at the Grand Canyon on the way home.

Should the demand justify it, a special train will also be provided from Chicago straight through to San Francisco to take care of those with whom time is a prime consideration.

The transportation committee of the Congress is further considering the possibilities of marine transportation by way of the Panama Canal. There appears to be a considerable demand for this, especially if satisfactory arrangements can be made for combining the land and water features.

## The International Engineering Congress of 1915

Under the auspices of the American Society of Civil Engineers, the American Institute of Mining Engineers, the American Society of Mechanical Engineers, the American Institute of Electrical Engineers and the Society of Naval Architects and Marine Engineers, there will be convened at the Panama-Pacific International Exposition, in 1915, an International Engineering Congress.

Engineers in all parts of the world have signified their intention of attending, and the delegation from Great Britain promises to be large in point of numbers and great in distinction.

The presidents and secretaries of the five organizations above named, together with eighteen other members, constitute the official body which will assemble and conduct the congress. Colonel George W. Goethals, chief engineer of the Isthmian Canal Commission, has consented to act as honorary president of the Congress, and will be in attendance in San Francisco when the celebration is held commemorating the completion of this great engineering achievement. The vice-presidents of the Congress will be selected from the most distinguished engineers of all the nations and with the president will form a body of men of the highest standing in the world of engineering.

The week of September 20-25, 1915, will be the time of the sessions of the International Engineering Congress, and the proceedings of the meetings will be preserved in permanent book form. These volumes will contain the papers contributed to the congress by eminent engineers and will embrace in their scope every line of engineering activity.

The executive offices of the congress are in the Foxcroft Building, San Francisco, where the following officers of the committee are located: W. F. Durand, chairman; W. A. Cattell, secretary-treasurer; E. J. Dupuy, executive secretary. The following are the chairmen of the sub-committees: C. F. Rand, Participation; W. F. Durand, Executive; W. G. Dodd, Finance; A. M. Hunt, Papers; W. A. Cattell, Publicity; E. H. Benjamin, Local Affairs.

A tentative schedule of general sessions has been formulated and the following

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sections will be considered: 1. The Panama Canal. 2. Waterways and Irrigation. 3. Railways. 4. Municipal Engineering. 5. Materials of Engineering Construction. 6. Mechanical Engineering. 7. Electrical Engineering. 8. Mining Engineering. 9. Naval Architecture and Marine Engineering. 10. Military Engineering. 11. Miscellaneous.

Each of these sections will hold independent sessions during the congress. Such joint sessions as may be deemed advisable will also be called. On account of the International Electrical Congress to be held September 13 to 18, 1915, just prior to the International Engineering Congress, the activity of the latter in the field of electrical engineering, assigned to Section 7, will be limited to consideration of the points of contact between electrical engineering and other engineering phenomena and work.

## Educational Committee

The Educational Committee of the Institute is devoting its energy to several interesting lines of work, all of which will be announced in due time. At present the coöperation of the members of the Institute is desired in assisting the Committee in securing all possible information regarding efforts being made at vocational training in different parts of this country and abroad, particularly as they relate to the electrical industry.

This coöperation might take one or more of the following forms:

(1) Suggestions as to vocational developments to be studied; school, college, industrial, public utilities.

(2) Data regarding the above.

(3) Suggestions to leaders in these movements that they send information to the Committee.

Communications should be addressed to Henry H. Norris, the chairman of the Committee, at Institute headquarters, in care of Secretary Hutchinson.

## Library Hours Lengthened

It has been suggested to the Library Board of the United Engineering Society that nine o'clock in the evening is too early an hour at which to close the library in the Engineering Societies Building, New York, which includes the individual libraries of the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers.

To test the effect of extending the hours, the executive committee of the Board has voted to keep the library open until ten o'clock during January, February and March.

## Directors' Meeting, January 9, 1914

The regular monthly meeting of the Board of Directors of the Institute was held at 33 West 39th Street, New York, on Friday, January 9, 1914.

There were present: President C. O. Mailloux, New York; Past-Presidents Gano Dunn and Ralph D. Mershon, New York; Vice-Presidents A. W. Berresford, Milwaukee, Wis., W. S. Murray, New Haven, Conn., and H. H. Barnes, Jr., New York; Managers F. S. Hunting, Fort Wayne, Ind., W. S. Lee, Charlotte, S. C., N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William B. Jackson, Chicago, Ill., William McClellan, New York, H. A. Lardner, San Francisco, Cal., B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $7,838.64 was ratified.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred seven members of

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the Institute to the grade of Fellow and twelve to the grade of Member, elected four applicants as Members and 74 as Associates, and ordered the enrolment of 94 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

The report of the Constitutional Revision Committee expressing its general sentiment that the best interests of the Institute will be served by not initiating this year any amendments to the Constitution, was read and accepted, with the understanding that the committee will formulate its recommendations of minor changes referred to in its report, for the use of any future similar committee.

President Mailloux stated that at the conference which took place in London last fall between the representatives of the Institute and the Institution of Electrical Engineers the suggestion was made that a Conference Committee be appointed to deal with all matters on which and regarding which concerted action between the two societies might be desirable. The matter was referred by Mr. Mailloux to the Standards Committee of the Institute, which committee recommended that a Conference Committee of three, with alternates, should be appointed by the President, to confer with a corresponding committee of the I. E. E. In accordance with this recommendation, the following members were appointed as the Institute's representatives and alternates on the proposed committee: A. E. Kennelly, H. M. Hobart, E. B. Rosa, C. A. Adams, and C. O. Mailloux, ex-officio.

Mr. H. H. Barnes, Jr., was unanimously reappointed by the Board as one of the Institute's three representatives on the Board of Trustees of the United Engineering Society, for the term of three years ending on the fourth Thursday of January, 1917.

The Secretary announced that in accordance with Section 21 of the Institute By-laws, President Mailloux would become a member of the John Fritz Medal Board of Award on the third Friday of January, vice Past-President Lewis B. Stillwell, whose term expires on that date.

## A. I. E. E. Meeting in New York January 9, 1914

The 290th meeting of the Institute, in the auditorium of the Engineering Societies Building, New York, January 9, 1914, was held as a joint meeting of the American Institute of Electrical Engineers and the New York Sections of the American Electrochemical Society and the American Society of Mechanical Engineers. The subject for consideration was "power problems in the electrolytic deposition of metals."

President C. O. Mailloux, calling the meeting to order at 8:25 p.m., said that such an opportunity was not often presented for discussing a problem involving different kinds of technical and engineering knowledge in a joint meeting of three technical engineering societies. He then called upon the authors to present their papers, which were given in the following order: "Limitations of the Problem of Electrolytic Deposition," by Mr. Lawrence Addicks, of the American Electrochemical Society; "The Power Problem in the Electrolytic Deposition of Metals," by Mr. H. E. Longwell, of the American Society of Mechanical Engineers; and "Sources of Direct Current for Electrochemical Processes," by Mr. F. D. Newbury, of the American Institute of Electrical Engineers.

Those who took part in the discussion were: Messrs. H. B. Coho, G. A. Roush, F. A. Lidbury, F. L. Antisell, J. B. F. Herreshoff, J. B. Herreshoff, C. O. Mailloux, Lawrence Addicks, C. H. Vom Baur, H. E. Longwell, and F. D. Newbury.

The meeting was then adjourned to the rooms of the Institute on the tenth floor, where light refreshments were served to the members of the three societies and their guests.

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### Recommended for Transfer, January 6, 1914

The Board of Examiners, at its regular monthly meeting on January 6, 1914, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO THE GRADE OF FELLOW

HENDERSON, S. E. M., Electrical Engineer, Canadian General Electric Co., Peterboro, Ont.

WILDER, CLIFTON W., Electrical Engineer, Public Service Commission, New York, N. Y.

TO THE GRADE OF MEMBER

ADAMS, JULIAN, Assistant Electrical Superintendent, Pacific Electric Railway Co., Los Angeles, Cal.

ADLER, M. G., Chief Draftsman, Los Angeles Aqueduct Power, Los Angeles, Cal.

BERTHOLD, MARTIN, Chief Engineer, Imperial Electric Co., Akron, Ohio.

BUTTERS, J. H., Engineer in chief, Hydro-Electric Power & Metallurgical Co. Ltd., Hobart, Tasmania.

### Transferred to the Grade of Fellow January 9, 1914

The following were transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on January 9, 1914.

ALLEN, C. E., Assistant Manager, D. & S. Dept., Westinghouse E. & M. Co., East Pittsburgh, Pa.

BERRESFORD, ARTHUR W., Vice-President and General Manager, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

CONN, CHARLES F., Assistant Manager, J. G. White Engineering Corp., San Francisco, Cal.

GRISSINGER, ELWOOD, Consulting Electrical and Mechanical Engineer, Buffalo, N. Y.

HARDING, CHARLES FRANCIS, Professor Electrical Engineering and Director, Electrical Laboratories, Purdue University, Lafayette, Ind.

LOZIER, ROBERT TEN EYCK, Vice-President General Manager, Central Service Corp., New York, N. Y.

TAYLOR, JOHN BELLAMY, Engineer, Foreign Dept., General Electric Co., Schenectady, N. Y.

Total, 7.

### Transferred to the Grade of Member January 9, 1914

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on January 9, 1914.

DWIGHT, HERBERT BRISTOL, Electrical Engineer, Canadian Westinghouse Co., Hamilton, Ont.

GUNBY, FRANK M., Special Assistant with Charles T. Main, Engineer, Boston, Mass.

HARRIES, GEORGE HERBERT, President, Louisville Gas & Electric Co., Louisville, Ky.

KENNEDY, MATTHEW G., Electrical Engineer, United Gas Improvement Co., Philadelphia, Pa.

KROGER, FRED H., Radio (Wireless) Engineer, National Electric Signaling Co., Brooklyn, N. Y.

MCDOWELL, CLYDE STANLEY, Lieutenant, U. S. Navy, Navy Yard, New York. N. Y.

MULLEN, JAMES J., Vice-President, Moloney Electric Co., St. Louis, Mo.

PARKER, LINDSAY R., Engineer of Stations, Toronto Hydro-Electric System, Toronto, Ont.

SCOTT, WIRT S., Electrical Engineer, Westinghouse E. & M. Co., East Pittsburgh, Pa.

SMITH, HAROLD HOOPER, Chief of Research Dept., Edison Storage Battery Co., Orange, N. J.

WAY, ASA P., Electrical Engineer, American Railways Co., Philadelphia, Pa.

WYMAN, WALTER SCOTT, Treasurer & General Manager, Central Maine Pwr. Co., Augusta, Me.

Total, 12.

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### Members Elected January 9, 1914

EAMES, CHARLES H., Principal, Lowell Textile School, Lowell, Mass.

FORD, HENRY H., Vice-President, McCarthy Bros. & Ford, Buffalo, N. Y.

SAXON, LOUIS, Electrical Engineer, Atlantic Gas & Electric Co., 25 Broad St., New York, N. Y.

VAN DYK, J. W., Managing-Director, Lindeteves-Stokvis, Amsterdam, Holland.

### Associates Elected January 9, 1914

ALDWORTH, EDWARD L., Waddell Mfg. Co.; res., 448 Fulton St., S. E., Grand Rapids, Mich.

ATKINSON, KERR, Instructor in Electrical Engineering, University of Missouri, Engineering Building, Columbia, Mo.

ATKISSON, LIEUT. EARL J., Director of Electrical and Mechanical Engineering, Engineer School, Washington Barracks, Washington, D. C.

BILLINGSLEY, F. N., Electrical Engineer, Transformer Dept., General Electric Co.; res., 54 Bartlett Ave., Pittsfield, Mass.

BRENNAN, W. D., Assistant General Manager, Union Pacific Coal Co., Cheyenne, Wyo.

BROOM, BENJAMIN A., Mechanical & Electrical Engineer, with William L. Steele, 400 United Bank Bldg., Sioux City, Iowa.

BURR, HARRY L., Electrical Inspector, New York, Westchester & Boston R. R.; res., 253 DeKalb Ave., Brooklyn, N. Y.

BUTCHER, A. M., General Foreman of Erection, Hydro-Electric Station, Gatun, Canal Zone.

BUTTERWORTH, ALLAN C., Electrical Draughtsman, Oliver Iron Mining Co., Duluth, Minn.

CARR, WALTER DEL., Construction Engineer, United Gas Improvement Co., Broad & Arch Sts., Philadelphia, Pa.

CHENEY, M. EDWARD, Electrical Engineer, Washington Surveying & Rating Bureau, 459 Colman Bldg., Seattle, Wash.

CLEVELAND, WILLIAM D., Superintendent, Telephone & Telegraph, Oregon Electric Railway Co.; res., 291 West Park St., Portland, Ore.

CONNALLY, JAMES G. M., Electrician, Western Canada Power Co., Carter Cotton Bldg., Vancouver, B. C.

CONNELL, EDWIN L., Electrical Engineering, Wagner Electric Mfg. Co.; res., 5702 Vernon Ave., St. Louis, Mo.

DERSHEM, ELMER, Student Engineer, Test Dept., General Electric Co.; res., 108 Victory Ave., Schenectady, N. Y.

DEXTER, HARRIS E., Student Engineer, General Electric Co., Schenectady, N. Y.

DOVER, ALFRED T., Chief Assistant Lecturer in Electrical Engineering, Battersea Polytechnic, London, England.

DUCHARME, FRANCIS LEONARD, Electrical Draughtsman, Stone & Webster Engineering Corp.; res., 25 Dalton St., Boston, Mass.

DUNCAN, MCKEE, Electrical Engineer, Duncan, Young & Pressey, Inc., 50 Church St., New York, N. Y.

EDGELL, W. T., JR., Electrical Engineer, General Electric Co.; res., 45 Linden St., Pittsfield, Mass.

ELFTMAN, J. D., Chief Engineer, St. Joseph Railway, Light, Heat & Power Co., St. Joseph, Mo.

EVERETT, FRANCIS DEWEY, Engineer, Westinghouse, Church, Kerr & Co.; res., 356 W. 57th St., New York, N. Y.

FAWELL, T. A., Electrical Engineer, Drafting Dept., General Electric Co.; res., 833 Locust Ave., Schenectady, N. Y.

FIELD, HORACE H., Superintendent, Connecticut Power Co., 33 Union St., New London, Conn.

FISHER, ROBERT B., Electrical Engineer, Consulting Engineering Dept., General Electric Co.; res., 702 Campbell Ave., Schenectady, N. Y.

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FRANK, CROSBY FIELD, Consulting Engineering Dept., General Electric Co.; res., 143 Lafayette St., Schenectady, N. Y.

FRYER, HERBERT, Sales Engineer, Babcock & Wilcox Co., 35 Federal St., Boston, Mass.

GOEBERT, ELMER C., Assistant Civil Service Examiner; res., 1713 W. Erie Ave., Philadelphia, Pa.

GRIFFITHS, L. C., Consulting Telephone Engineer, Aurora, Ill.

HAGGAN, E. A., Editor, *Mining, Engineering and Electrical Record*, 1104 Dominion Building, Vancouver, B. C.

HARBIN, GEORGE F., Associate Professor of Electrical Engineering, The Catholic University of America; res., 11 Seventh St. S.E., Washington, D.C.

HEBBERT, C. E., Engineering Assistant, Public Service Electric Co., Newark; res., 16 Carlton Place, Passaic, N. J.

HELMREICH, L. W., Head of Electrical Dept., Ranken Mechanical School, St. Louis, Mo.

HENTZ, ROBERT A., Assistant, Station Construction Dept., Philadelphia Electric Co.; res., 4615 Sansom St., Philadelphia, Pa.

HILLEGASS, HERBERT H., Instructor in Electrical Engineering, Delaware College, Newark, Del.

HULL, FREDERICK D., Telephone Development Engineer, Western Electric Co., Chicago, Ill.

HUMPHREY, H. K., Assistant Consulting Engineer, Consulting Engineering Dept., General Electric Co., Schenectady, N. Y.

HUTCHINS, RICHARD A., Designing Engineer, Railway Motor Engineering Dept., General Electric Co.; res., 328 Glenwood Blvd., Schenectady, N. Y.

ITO, KEIJI, Assistant Professor, Tokyo Technical College, Tokyo, Japan.

KANTORWITZ, HARRY, Draftsman, Light & Development Co. of St. Louis; res., 3955 Hartford St., St. Louis, Mo.

KERRICK, HARRISON S., Coast Defense Artillery Engineer, U. S. Army, Fort Hamilton, Brooklyn, N. Y.

KNUTZ, WILL H., Electrical Inspector, Public Service Co. of Northern Illinois, 1721 West End Ave., Chicago Heights, Ill.

KOHL, GEORGE H., Electrical Engineer, Ritchie, Agnew & Co., Prince Rupert, B. C.

KUTNER, S. D., Inspector, Testing Dept., N. Y. C. & H. R. R. R. Co.; res., 600 W. 165th St., New York, N. Y.

LAMOREE, C. D., Sales Engineer, Westinghouse Electric & Mfg. Co., 811 I. N. Van Nuys Bldg., Los Angeles, Cal.

LINDAHL, CARL ROBERT, Assistant Superintendent, Peninsular Power Co., Iron River, Mich.

LOCKE, DEAN J., Assistant Engineer with A. S. Richey, Worcester Polytechnic Institute, Worcester; res., Sturbridge, Mass.

LOHSE, ALFRED C., Works Engineer, Whitman & Barnes Mfg. Co.; res., 9973 Throop St., Chicago, Ill.

LONG, CARL C., Station Superintendent, Utah Power & Light Co., Grace, Idaho.

MILLER, LORIN G., Massachusetts Institute of Technology; res., 261 Newbury St., Boston, Mass.

MITTAG, ALBERT H., Electrical Engineer, Consulting Engineering Dept., General Electric Co.; res., 448 McClellan St., Schenectady, N. Y.

MONTSINGER, V. M., Electrical Engineer, General Electric Co., Pittsfield, Mass.

MOORE, HOWARD J., Chief Electrician, Newbury Steel Works, American Steel & Wire Co., Cleveland, Ohio.

OAKES, ARCHIE, Electrical Engineer, American Electrical Heater Co., 1351 Woodward Ave., Detroit, Mich.

OTTMAN, ROBERT E., Engineer, Cutler-Hammer Mfg. Co., Milwaukee, Wis.

PASCOE, HOWARD N., with A. S. Richey, Worcester Polytechnic Institute, Worcester, Mass.

PENN, MARION, Student Engineer, Testing Dept., General Electric Co.; res., 711 Nott St., Schenectady, N. Y.

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RENNIE, WALTER M., Draftsman, with Gardner S. Williams; res., 1341 Wilmot St., Ann Arbor, Mich.

SCHAEFER, CLARENCE C., Engineering Dept., Department of City Transit; res., 1920 W. Somerset St., Philadelphia, Pa.

SPRATT, W. C., Designing Engineer, Railway Engineering Dept., General Electric Co.; res., 1 State St., Schenectady, N. Y.

STEERE, LUCIUS ESEK, JR., Assistant to Manager, Service Dept., Wagner Electric Mfg. Co.; res., 6158 Gambleton Place, St. Louis, Mo.

SWOBODA, H. O., Consulting Electrical and Mechanical Engineer, Pittsburgh; res., 327 Locust St., Edgewood, Pittsburgh, Pa.

THIELE, ERNEST J., Railway & Traction Engineering Dept., General Electric Co.; res., 431 Smith St., Schenectady, N. Y.

THOMPSON, ALEX. C., Foreman of Erection, Chapman & Walker, Ltd., Richmond St., Toronto, Ont.

TIVEY, J. P., Engineer, Railway & Traction Engineering Dept., General Electric Co., Schenectady, N. Y.

TROTT, ALFRED, Erecting Dept., Canadian Westinghouse Co.; res., 2200 7th Ave. W., Vancouver, B. C.

WALKER, ALBERT S., Assistant Resident Engineer, G. T. P. Ry. Co. Dry Dock, Prince Rupert, B. C.

WARD, ARTHUR THOMAS, Experimental Chemist, U. S. Metals Refining Co., Chrome, N. J.

WARD, JOSEPH EVANS, Electrical Engineer, Railway Equipment Engineering Dept., General Electric Co.; res., 841 Union St., Schenectady, N. Y.

WENGER, THEODORE L., Efficiency Engineer, Engineering Supervision Co.; res., 250 Manhattan Ave., New York, N. Y.

WHEELER, FREDERICK S., Electrical Engineer, Railway & Traction Engineering Dept., General Electric Co., Schenectady, N. Y.

WOODMAN, F. W., Assistant Superintendent, Winnipeg Electric Ry. Co., Pinawa, Man., Canada.

WOOSTER, ROY N., Engineer, Construction Engineering Dept., General Electric Co.; res., 702 Campbell Ave., Schenectady, N. Y.

YOUNG, CHARLES N., Student Engineer, Testing Dept., General Electric Co.; res., 110 Nott Terrace, Schenectady, N. Y.

Total 74.

## Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1914.

Allum, J., Dunedin, N. Z.
Atkinson, O. C., Gatun, C. Z.
Bahlmann, E. F., Milwaukee, Wis.
Barker, C. M., Worcester, Mass.
Beaver, J. L., Philadelphia, Pa.
Blair, F. W., New York, N. Y.
Boyer, R. H., Pittsfield, Mass.
Bradley, H. C., Ft. Wayne, Ind.
Broe, A. L., Harrison, N. J.
Brownell, R. A., Lincoln, Nebr.
Brunt, A. E., Pittsburgh, Pa.
Buchaca, E.J. (Member), Syracuse, N.Y.
Bundy, E. S., Solvay, N. Y.
Chapp, J. J. Chicago, Ill.
Christensen, C. P., Kalispell, Mont.
Code, A. G., Hamilton, Ont.
Cooke, M. T., Jr. (Member), Phila., Pa.
Cowles, R. R., Oakland, Calif.
Cox, W. N., Philadelphia, Pa.
Cully, W. L. New York, N. Y.
Curtner, D. L., Lafayette, Ind.
Dickson, W.S. (Member), New York, N.Y.
Diesem, L. C., Schenectady, N. Y.
Dimock, A. H., Seattle, Wash.
Dinter, H. A., Hico, Texas.
Dowey, T. L., New York, N. Y.
Dresser, S. R., New York, N. Y.
Dye, I.W. (Member), Pedro Miguel, C.Z.
Elliott, S. S., Corozal, C. Z.

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Ellwanger, E., Chicago, Ill.
Erdmann, M. H., New York, N. Y.
FitzGerald, F. A. J. (Member), Niagara Falls, N. Y.
Foersterling, F. J., Peoria, Ill.
Foote, A. H., Chicago, Ill.
Francis, L. L., Kansas City, Mo.
Fukagawa, K., Formosa, Japan.
Gaines, S. N., E. Pittsburgh, Pa.
Gardiner, T. B., Miraflores, C. Z.
Garrett, J. H., Corozal, C. Z.
Giroux, R. M., Schenectady, N. Y.
Goodman, M. D., New York, N. Y.
Grauer, J. G., Philadelphia, Pa.
Gray, H. J., Vancouver, B. C.
Graybill, J. H., Pittsburgh, Pa.
Hagenlocher, E., New York, N. Y.
Hague, F. T., Pittsburgh, Pa.
Haines, J. M., Wilkes Barre, Pa.
Hanson, E. C. A., Saskatoon, Sask.
Harding, G. (Member), Spokane, Wash.
Harger, C., Iron Mountain, Mich.
Hatch, R. S., Chicago, Ill.
Heaton, H. C. (Member), Chicago, Ill.
Hirdler, F. C., Oklahoma City, Okla.
Hobson, A. J., Gatun, C. Z.
Hollingsworth, G.R.,Pedro Miguel,C.Z.
Holloway, F. J. H., Sydney, Australia.
Holmes, H. A., Newport, R. I.
Jackson, N., Philadelphia, Pa.
Jefferson, W. H., Milwaukee, Wis.
Juncker, E. W., Curimeo, Mich., Mex.
Kemp, H. D., Boston, Mass.
Kendall, R. T., Jackson, Mich.
Kennedy, H.J. (Member),Seattle,Wash.
King, E. E., Los Angeles, Cal.
King, G. A., Newark, N. J.
King, R. P., Newark, N. J.
Klippel, F. H., Tonopah, Nev.
Kollock, G. J., Atlanta, Ga.
Lee, C. K., Bowling Green, Mo.
Leeper, J. P., Pittsburgh, Pa.
Leslie, W. T., Montreal, Quebec.
MacTavish, H. J., Toronto, Ontario.
Man, G. A., Cleveland, Ohio.
Maxwell, M., Schenectady, N. Y.
McDonald, E. C., Pedro Miguel, C. Z.
McMillan, F. O., Schenectady, N. Y.
Merriman, H. O., Hamilton, Ont.
Moore, J., Seattle, Wash.
Munroe, R. B., Provo, Utah.
Newton, W. L., Pasadena, Cal.
Nutt, A. M., Pittsburgh, Pa.
Parker, G. C., Toronto, Ont.
Parker, H. V., Gatun, C. Z.
Perry, O. M., Windsor, Ont.
Phillips, C. E., Norwood, Ohio.
Porter, J. B., (Member), Phila., Pa.
Prescott, R. D., Panama City, Panama.
Randolph, H. F. (Member), Pittsburgh, Pa.
Rinehart, O. B., Ft. Wayne, Ind.
Robinson, P. W., Schenectady, N. Y.
Schwegmann, J. F., Tyler, Tex.
Shanklin, S., Philadelphia, Pa.
Shaw, C. L., Manton, Calif.
Shoester, G. W., Camden, N. J.
Sjoblom, A. T., Corozal, C. Z.
Sylvester, W., West Allis, Wis.
Thomas, B. F. Jr., Webster Groves,Mo.
Tramm, W. H., Ann Arbor, Mich.
Wallace, J. N. (Member), Antwerp, Belgium.
Warner, E. M., Washington, D. C.
Watson, H. L., West Lynn, Mass.
Weiss, F. C., Birmingham, Ala.
Welch, G. R., Corozal, C. Z.
Wells, C. J., Milwaukee, Wis.
Williams, W. J. (Member), Shanghai, China.
Zengerle, J. C., New York, N. Y.
Total 106.

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**Students Enrolled January 9, 1914**

6226 Casler, W. B., Univ. of Mich.
6227 Crawford, W. E., Univ. of Mich.
6228 LaFever, H. H., Univ. of Mich.
6229 McCabe, G. B., Univ. of Mich.
6230 Baits, S. G., Univ. of Mich.
6231 Loughead, R. C., Univ. of Mich.
6232 Ely, H. B., Univ. of Mich.
6233 Moon, F. L., Univ. of Mich.
6234 Perry, L., Univ. of Mich.
6235 Kuebler, E. G., Univ. of Mich.
6236 Groetzinger,C.,Case Sch. App. Sci.
6237 Harmount,H.S.,CaseSch.App. Sci.
6238 Burgess,P.W.,WorcesterPoly.Inst.
6239 Rumbaugh,R.M.,CaseSch.App.Sci
6240 Arps, E. J., Univ. of Wisconsin.
6241 Raitt, C. C., Univ. of Cincinnati.
6242 Hadley, D. J., McGill Univ.
6243 Lloyd, A. M., Ohio State Univ.
6244 Wohrley, J. R., Ohio State Univ.
6245 Shamel, F. R, Ohio State Univ.

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6246 Levitin, B., Ohio State Univ.
6247 Randall, H. K., Ohio State Univ.
6248 Smith, A., Ohio State Univ.
6249 Huff, J., Ohio State University.
6250 Pyle, T. H., Ohio State Univ.
6251 Ganschow, L. W.,OhioStateUniv.
6252 Barrett, W. M., Ohio State Univ.
6253 Foster, W. H., Oregon Agri. Coll.
6254 Corkins, V. G., Oregon Agri. Coll.
6255 Marx, L.,Oklahoma A. & M. Coll.
6256 Wortman, R.B.,Okla.A.&M.Coll.
6257 Wood, R. A., Okla. A. & M. Coll.
6258 Brown, O. C., Okla. A. & M. Coll.
6259 Graham, Q., Okla. A. & M. Coll.
6260 Brooks, J. C., Worcester PolyInst.
6261 Wells, A. R., Univ. of Toronto.
6262 Ferguson, R.S.,Throop Coll.Tech.
6263 Gregg, P. F., Iowa State Coll.
6264 Hudson, W. F., Iowa State Coll.
6265 Kelly, C. M., Jr., Univ. of Maine.
6266 Krug, F., Cooper Union.
6267 Shanly, W.E.,Univ.ofWashington.
6268 Grossbord, S., Univ. of Colorado.
6269 Chaudhuri, D. K., Univ.of Wash.
6270 Burns, A. H., Worcester Poly.Inst.
6271 Ornauer, R. A., Univ. of Colorado.
6272 Mahoney, W. L., Univ. of Minn.
6273 Anderson, G. W., Univ. of Penn.
6274 Anderson, R. T., Univ. of Penn.
6275 Beck, C. J., Univ. of Penn.
6276 Butler, H., Univ. of Penn.
6277 Cleeland, R., Univ. of Penn.
6278 Fernandes, J. M., Univ. of Penn.
6279 Grosner, G. D., Univ. of Penn.
6280 Leech, R. W., Univ. of Penn.
6281 McAfee, W. K., Univ. of Penn.
6282 McLeeman, J.C.E.,Univ.of Penn.
6283 Poalk, J. L., Jr., Univ. of Penn.
6284 Ritter, R. W., Univ. of Penn.
6285 Salles, J. de A., Univ. of Penn.
6286 Swingle, W. S., Univ. of Penn.
6287 Zimmermann,J.Jr.,Univ. of Penn.
6288 Zimmermann,W.J.,Univ. of Penn.
6289 Irwin, R. E., Case Sch. App. Sci.
6290 Matthews, R.G.,Univ.of Toronto.
6291 Campbell, H. A.,Univ.of Toronto.
6292 Kewin, G. E., Univ. of Toronto.
6293 Baker, A. D., Univ. of Mich.
6294 Braistel, L., Univ. of Mich.
6295 Bice, W. L., Univ. of Mich.
6296 Miller, G. E., Univ. of Mich.
6297 Stubbs, H. W., Univ. of Mich.
6298 Brush, S. R., Univ. of Mich.
6299 Mowrer, C. E., Univ. of Mich.
6300 Marshall, E. T., Univ. of Mich.
6301 Vernor, W. M., Univ. of Okla.
6302 Clark, R. W., Univ. of Okla.
6303 Karcher, J. C., Univ. of Okla.
6304 Martin, G. D., Univ. of Okla.
6305 Dunbar, R. E.,CarnegieInst.Tech.
6306 Smith, H. M., Case Sch. App. Sci.
6307 Gardner, C. W., CaseSch.App.Sci.
6308 Darland, A. F., Univ. of Wash.
6309 Fowler, W. D., McGill University.
6310 Webster, A., Montana State Coll.
6311 Gabree, J. V., Wentworth Inst.
6312 Diamant, N. S., Union Coll.
6313 Evans, D. L., Jr., Stanford Univ.
6314 Ward, B. E., Stanford Univ.
6315 Bradford, W. M. Stanford Univ.
6316 Burbeck, W. B., Stanford Univ.
6317 Hardy, C. C., Wash. Univ.
6318 Sweet, L. M., Wash. Univ.
6319 Rader, R., Univ. of Wash.

## Past Section Meetings

### Chicago

A joint meeting of the Electrical Section, Western Society of Engineers, and Chicago Section, A. I. E. E., was held Monday evening, November 24, 1913. The meeting was called to order by Mr. D. W. Roper, chairman of the Chicago Section A. I. E. E., with about fifty members and guests in attendance.

A paper was presented by Mr. L. B. Andrus, on "Testing of Horizontal Low-Head Water Turbines." Discussion followed by various members.

The next meeting of the two organizations was held Monday evening, December 29, with about 40 members and guests in attendance. Mr. H. W. Young presented a paper on "Moderate Capacity Outdoor High-Tension Substations," illustrated by lantern slides. A discussion followed, by Messrs. Wingard, Perry, Jackson, Roper, Lloyd, Cravath, Gear, Allen and others.

### Detroit-Ann Arbor

The subject of public utilities was discussed at a meeting of the Detroit-Ann Arbor Section held in the Physics

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Building, University of Michigan, Ann Arbor, Mich., on December 5. The program was so arranged that the papers would present two controversial sides of the question. The meeting was highly successful, there being about 178 people present, including representatives of a number of public utility corporations who had been invited in order that they could present their side of the matter.

The papers presented were as follows: "Factors Determining a Reasonable Charge for Public Utility Service," by Mortimer E. Cooley, dean of the engineering department, University of Michigan; "Financial versus Engineering Estimate of the Value of a Public Utility," by George W. Patterson, professor of electrical engineering, University of Michigan. The discussion was participated in by the following: Messrs. Lawton T. Hemans, chairman of the Michigan State Railroad Commission, Gardner S. Williams, consulting engineer; G. M. Welch, commercial superintendent of the Michigan State Telephone Company; A. D. Spencer, chief statistician of the Edison Electric Illuminating Company of Detroit; and Robert B. Rifenberick, engineer, Detroit United Railways.

### Los Angeles

The Los Angeles Section held a meeting on December 29, 1913, when no formal papers were presented, the occasion being devoted to an inspection of automatic and manual telephone plants.

The members and guests, to the number of 96, met first at the main exchange of the Home Telephone and Telegraph Company, which is one of the largest automatic exchanges in the country. The plant system was explained by Mr. L. W. Kellar, the chief engineer, and his assistants.

The party then went to see the main exchange of the Pacific Telephone and Telegraph Company, where the plant is entirely manual, and were entertained in like manner by Mr. Dix, chief engineer, and his staff.

The members expressed their appreciation of this opportunity to study the two types of plant, and voted it one of the most interesting meetings the Section has held.

### Lynn

Mr. E. R. Barry, the chairman, opened the meeting of the Lynn Section on December 17, introducing Professor H. E. Clifford, professor of electrical engineering at Harvard University. Professor Clifford's subject was "Sympathetic Vibrations, with Some Electrical Applications." He had had apparatus installed for the purpose of illustrating his remarks, and the points brought out, with the assistance of this apparatus, were made clear to all present.

Professor Clifford began by calling attention to two classes of waves, the traveling and the standing or stationary. The first may be induced by a variety of causes, but is always of momentary duration. On the other hand, the stationary wave is of longer duration and is the result of a certain definite cause and in its electrical form may cause trouble often of a serious or dangerous nature. He showed how a standing sound wave could be established by the use of tuning forks of the same pitch, the vibration being communicated from one to the other and continuing after the one struck first had been dampened. However, when the vibrations were communicated to a fork of different pitch, although some response could be gotten by forcing the impact, this response was of short duration.

Another interesting experiment was illustrated by means of a score of glass balls, showing that the same kind of impulse given to the *first in the row* was always slower at the end of the line. Resonators were shown which responded to sympathetic waves, but to other waves, not in tune, refused to give out their keynote.

The sympathetic flame was of great interest to the audience. This was a gas flame about 18 inches high, which, while not sensitive to ordinary musical

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tones, was markedly affected by certain sounds, especially by the note produced by striking upon metal with a hammer. Some of the metal bars used gave out vibrations beyond the range of the human ear. Professor Clifford showed how waves could be produced by mechanical means, and for this purpose brought into use several arrangements of pendula, rubber tubes, etc. The lecturer followed his illustrations by an explanation of the analogy between the phenomena shown and the electrical disturbances which are manifested when electrical waves are set up in apparatus while in operation, and showed how the same characteristics were true of both the mechanical and electrical waves.

This meeting was held in Burdett Hall, and was attended by 189 members and visitors.

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At the next meeting of the Section, on January 12, the speaker was Professor E. E. F. Creighton of Union University, Schenectady.

Professor Creighton began his lecture with a brief synopsis of waves, stating that the electrical are very much simpler than the sea waves, but because we are so familiar with the latter, they excite little interest. He drew a sharp distinction between a surge and a series of waves, illustrating this by means of charts and the usual long spiral spring. By means of his wave motion machine, the composition of two traveling waves into a standing wave was clearly shown.

The production of a standing electrical wave was then shown by means of a vertical glass cylinder wound with wire, which was made to oscillate by connection with an ordinary oscillation circuit. The voltage along the cylinder was read by means of a neon tube, which glowed at different brilliancies for the varying voltages. The sine wave form was traced by making the tube follow the path where it was just on the point of glowing. The nodes and peaks of the standing wave were clearly shown, and by changing the inductance of the surge circuit, different frequencies were impressed which caused standing waves of different lengths.

Professor Creighton then took up lightning arresters, explained their function and went into details concerning the operation of the principal types. The recently developed oscillation transformer for testing insulators was used to impress artificial lightning upon an insulator, which became covered with corona. A multigap lightning arrester was then connected, relieving the insulator of the brush discharge, and finally an aluminum lightning arrester, which took the entire discharge noiselessly.

The harmlessness to human life of these high-frequency discharges was shown by Mr. Creighton's assistant, Mr. C. Field Frank, who took the discharge for several minutes through his body, making contact with a pair of pliers held about two inches from one terminal. The frequency of this discharge was about 200,000 cycles, and the voltage was sufficient to jump a 12-inch needle gap.

The meeting was held at the General Electric Company's works at West Lynn, and was attended by 267 members and 75 visitors.

### MILWAUKEE

The Milwaukee Section held a meeting on December 10, at which Mr. Arthur J. Sweet presented a paper entitled "An Analysis of Street Lighting Requirements."

Chairman L. E. Bogen presided, and the total attendance was 142. The meeting was held at the Plankinton House.

### MINNESOTA

The regular monthly meeting of the Minnesota Section was held at the main engineering building of the University of Minnesota, on Monday, December 15, 1913.

The first paper of the evening was entitled "New Developments in Transmission Line Practise and Equipment"

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by Mr. R. A. Lundquist, consulting engineer, author of "Transmission Line Construction." This paper presented the state of the art down to the present time.

The next paper was entitled "Line Disturbances and Protection from Electrical Storms," by Mr. Lincoln Nissley, engineer of the H. M. Byllesby Company. This paper presented a vast amount of new material for consideration and contained many valuable data secured during the storm at Hugo, Minnesota, on July 4, 1913.

Chairman W. T. Ryan presided, and the total attendance was 48.

### Panama

The initial meeting of the Panama Section was held at the Hotel Tivoli, Panama, on December 7, 1913. There were 38 present, of whom 25 were Institute members. Mr. W. R. McCann acted as temporary chairman, and Mr. R. H. Whitehead as temporary secretary.

A letter from Secretary Hutchinson was read, dated October 15, 1913, transmitting a notification of the authorization of the Panama Section by the Board of Directors of the Institute. The temporary chairman then called for nominations of officers. Mr. Edward Schildhauer, Fellow of the Institute, was unanimously elected chairman, and presided during the rest of the meeting. The other officers were then elected, unanimously, as follows: vice-chairman, E. E. Lee; secretary-treasurer, W. H. Rose; executive committee, F. C. Clark, W. R. McCann, Hartley Rowe.

A resolution was passed, empowering the chairman to appoint a committee of three to draw up by-laws for the Section. It was the consensus of opinion that a separate committee on papers should be formed, subordinate to the executive committee. After further discussion of plans, the meeting adjourned.

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The second meeting of the Panama Section was held on the afternoon of January 4, in the Lock Model Room at Ancon, with a total attendance of 34.

Chairman Schildhauer announced that Mr. W. H. Rose had declined to act as secretary-treasurer of the Section. Mr. W. R. McCann was thereupon elected to that office, and Mr. A. B. Kratz was elected as a member of the executive committee, vice Mr. McCann. The committee on by-laws reported a draft, which was adopted, with minor modifications, as the by-laws of the Section.

Mr. William Baxter delivered a lecture on the Panama Canal and the models exhibited in the Model Room. Mr. Warren E. Hoffman then abstracted the paper on *Operation of Transmission Lines*, by Lee Hagood, published in the December, 1913, Proceedings. The subject was discussed by Messrs. Whitehead, McCann, Schildhauer, Rowe, Lee, Clark, Ovalle, Grier, Ely and others.

### Philadelphia

A meeting of the Philadelphia Section was held on November 10, 1913, at the Engineers' Club, with 82 members and visitors attending. Chairman A. R. Cheyney announced the appointment of chairmen of committees, as follows: Meetings and Papers, W. F. James; Educational, Professor George A. Hoadley; Public Policy, J. F. Stevens; Telephone and Telegraph, H. Mouradian; Electrophysics, H. Clyde Snook; Membership, Hugh Leslie; Railway, W. C. Kerr; High-Tension Transmission, Harold Goodwin; Power Station, Paul Spencer; Industrial Power, Kern Dodge; Electrochemical, Professor Carl Hering; Relations of Consulting Engineers, Charles E. Bonine; Sections, H. A. Hornor; Entertainment and Sociability, L. J. Costa; Finance, George Ross Green; Publicity, Mr. Tracy.

The subject of the evening, "The Classical-Scientific vs. the Purely Technical Course for the Electrical Engineer," was opened by a paper presented by Dr. Howard McClenahan, followed by papers by Professors R. H. Fernald

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and Arthur J. Rowland. A discussion followed, in which Professors Hoadley, Kershner, Rittenhouse, Ives, Fernald, Rowland and Messrs. Leeds and Trautwine took part.

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The Section held a meeting on January 12, at the Engineers' Club. Chairman A. R. Cheyney presided, and the total attendance was 110.

The subject of the evening was "Coupled Circuits, or the Problem of the High-Frequency Transformer in Wireless Telegraphy," presented by Dr. W. S. Franklin. Dr. Franklin's lecture was illustrated by models, experiments and lantern slides.

### PITTSBURGH

The Pittsburgh Sections of the A. I. E. E. and the Illuminating Engineering Society held a joint meeting on December 12, 1913, in the auditorium of the Engineers' Society of Western Pennsylvania, in the Oliver Building. The presiding officers were Messrs. A. M. Dudley and C. J. Mundo, chairmen of the two Sections.

Three papers were presented by central station engineers, as follows: "A Problem in Boulevard Lighting," by J. M. Froelich, a description of the first tungsten system of boulevard lighting in Pittsburgh; "Variables in Street Lighting," by J. F. Martin, a service paper discussing factors which make up successful street illumination; and "Some Aspects of Free Lamp Renewals," by T. F. Campbell, an outline of the policy of central stations in regard to free lamp renewals, and the present policy as to free tungstens.

The meeting proper was preceded by an informal talk by Mr. W. A. Darrah of the Westinghouse Electric and Manufacturing Company, on some fundamental technical considerations of illumination. The following men contributed to the discussion: Messrs. Muller, Swoboda, Magdsick, Hower, Hurley, Pinkerton, Turpin, Chillas, Bright, Darrah, Rolph, Doane, Cotton, Keeting and E. C. Stone.

The total attendance at the meeting was 125.

### PITTSFIELD

The third meeting of the Pittsfield Section was held on Thursday, November 20, 1913, at the Berkshire Athenaeum. Mr. F. W. Peek, Jr., of the consulting engineering department of the General Electric Company, gave a talk on the subject of "Some High-Voltage Engineering Problems." Mr. Peek discussed the dielectric circuit and mechanism of breakdown in gaseous, liquid and solid insulations. Among the problems of high-voltage engineering discussed were the breakdown caused by addition of stronger insulations, the limitations imposed upon transmission voltages by line and apparatus, transient voltages and their effects, and the sphere gap as a means of measuring high voltages.

Chairman John J. Frank presided at this meeting, which was attended by 40 Institute members and 50 local members of the Section.

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The fourth meeting of the Pittsfield Section was held at the Berkshire Athenaeum on Wednesday, December 10. The speaker of the evening was Mr. P. Junkersfeld of the Commonwealth Edison Company of Chicago, who took as his subject, "The Responsibilities of Electric Power Companies." Mr. Junkersfeld brought with him a number of extremely interesting lantern slides, showing graphically the various activities of the Commonwealth Edison Company, as well as other power companies in Illinois.

Chairman Frank presided, and the total attendance was 105.

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The fifth meeting of the 1913-1914 season of the Pittsfield Section was held in the Berkshire Athenaeum on Friday, January 2. The speaker of the meeting was Mr. John B. Taylor, who until recently was the engineer of the foreign department of the General

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Electric Company, but is now engaged in consulting work. The subject of Mr. Taylor's talk was "Color Photography," which was illustrated by a large number of color slides which proved to be of great interest. These slides showed in detail the construction of the various kinds of plates used in this work, as well as the results which may be obtained by their means.

Chairman Frank presided, and the total attendance was 83.

### St. Louis

A meeting of the St. Louis Section was held at the Engineers Club of St. Louis on the evening of December 10, 1913. This was the eighty-sixth meeting of this Section. Chairman F. J. Bullivant presided. There were present 18 members and 39 guests.

The speaker of the evening was Mr. H. W. Eales, assistant engineer of the electrical department of the Union Electric Light and Power Company of St. Louis. Mr. Eales gave a description of "The Utilization of Keokuk Water Power by the Union Electric Light and Power Company." Several lantern illustrations added to the interest of the paper. A brief discussion followed.

### Schenectady

The Schenectady Section held a meeting on December 5, 1913, in the Edison Club Hall, at which the attendance was 275, including 25 visitors. Chairman G. H. Hill presided.

Dr. E. Weintraub presented a paper on "Boron," illustrated with experiments and lantern slides, and treating of the peculiar electrical characteristics of boron. Many useful applications were suggested.

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The next meeting was held on December 16 in the same place, with Chairman Hill presiding, and the total attendance was 400.

Mr. W. L. R. Emmet presented a paper entitled "Power from Mercury Vapor," in which he described a process by which the power output from heat energy may be increased by nearly 50 per cent over the best practise in modern steam plants. The subject was further discussed by Dr. Ernst J. Berg and Mr. D. B. Rushmore.

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The 136th meeting of the Schenectady Section was held on January 6, at the same place.

The speaker was Mr. A. E. Ellis, who gave a lecture on "The Use of the Microscope in Science and Industry," illustrated with lantern slides. This was followed by a few remarks by Mr. John B. Taylor, on the pleasure to be derived from the use of the microscope.

A demonstration was then given, over fifty microscopes with exhibits having been provided for the use of those present. Mr. Taylor also demonstrated his projecting microscope.

Chairman Hill presided, and the total attendance was 275.

### Seattle

The Seattle Section held a meeting on December 16, 1913, at the Chamber of Commerce. Chairman J. D. Ross presided, and the total attendance was 28.

The paper of the evening was read by Mr. John R. King, entitled "Electrically Driven Vehicles," giving an interesting comparison of the various types and methods of operation. The paper was illustrated with stereopticon slides and was discussed at some length by Mr. Higgins and Mr. Wing, automobile men of Seattle, as well as Messrs. Lindsay, Howes, Ross and other Institute members.

### Spokane

The Spokane Section held its regular monthly meeting on November 21, 1913, in the physics lecture room of the Lewis and Clark High School. The Section chairman, Mr. J. B. Fisken, presided, and the total attendance was 49.

A paper by Mr. Max Passler of the Spokane and Inland Empire Railway, on the "Single-Phase Commutator

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Railway Motor," was read and discussed at length. Mr. Passler's paper described the component parts of the motors in use on the S. & I. E. R. system, showing where difficulties had been encountered and how they had been remedied.

### Toledo

The Toledo Section held a meeting on January 9, at the Toledo Commerce Club, at which the speaker was Dr. C. M. Harpster, physician for the Doherty Company.

Dr. Harpster's subject was " The Use of the Pulmotor in Electrical Accidents." He said that whereas a great deal has been heard about " conservation of natural resources," not until lately has much been done for the conservation of human life, the most valuable asset of all. He said that 49,552 deaths in the United States annually are due to violence, and that statistics of the percentages of accidents in civil occupations showed that the figure for the electrical trades was 6.3 per 1000.

Dr. Harpster then discussed the different effects of direct currents of low and high voltages, and alternating currents of different voltages and frequencies, upon the body. The two chief causes of death from electric currents are cardiac fibrillation and respiratory paralysis. Low-tension currents tend to kill chiefly through cardiac fibrillation, and as the voltage is increased the effect upon the heart becomes less pronounced, but at the same time the effect upon the central nervous system becomes more and more pronounced. So that with high-tension currents death is more likely to be caused by respiratory failure, although if the contact is prolonged, the heart is also stopped.

Cardiac fibrillation is fatal in spite of all known methods of treatment. In cases of simple respiratory paralysis the patient may be kept alive by artificial respiration until the nervous system recovers. The Schäfer prone pressure method of resuscitation was fully explained and demonstrated, and a pulmotor was also exhibited and explained. Dr. Harpster also spoke of the care of burns and other " first aid " measures. The meeting was then thrown open for discussion, which was participated in by many of those present.

Chairman George E. Kirk presided at this meeting, at which the total attendance was thirty.

### Toronto

The first regular meeting of the Toronto Section for the season was held at the Engineers' Club, Toronto, on the evening of December 19, 1913.

The following officers were elected for the ensuing year: Mr. D. H. Mc Dougall, chairman; Mr. W. F. Wright, vice-chairman; Mr. H. T. Case, secretary; Messrs. H. U. Hart, E. I. J. Brandon and P. E. Hart, members executive committee.

A paper on " Steam Turbines " was presented by Mr. T. E. Keating. This address was illustrated by numerous lantern slides, and was followed by general discussion in which Messrs. Black, Wright, Hughson and Case participated.

This meeting was attended by 42 members and visitors.

### Urbana

The Urbana Section held a business meeting on December 12, 1913. The special committees reported on the new by-laws for the Section, which were adopted with only a few minor changes. Chairman Morgan Brooks presided, and the attendance was eight.

### Vancouver

The Vancouver Section held a regular monthly meeting in the University Club rooms on December 19, 1913, at which Mr. J. H. Paget presented a paper on " Switchboard Instruments." This paper described the principles of operation and gave a description of the various types of voltmeters, ammeters, wattmeters, power factor meters and graphic recording instruments.

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Mr. E. M. Breed, chairman, presided at this meeting. The total attendance was 32.

WASHINGTON, D. C.

The meeting of the Washington Section, held on January 15, in the Telephone Building, was addressed by Dr. Herbert E. Ives, of Philadelphia, who made some interesting prophecies on "The Lighting of the Future." He indicated that the lines of physical research of the present time might lead to methods being devised to control the distribution of energy in the spectrum of artificial light sources, so that the large portion of energy now in the invisible part might be shifted to the visible part.

He also gave some interesting notes on experiments to reproduce by artificial means the distribution of light which normally occurs in daylight illumination from windows.

Chairman H. C. Eddy presided. The meeting was attended by 61 members and visitors.

## Past Branch Meetings

COLORADO STATE COLLEGE

The Colorado State College Branch held a meeting on January 8, when Mr. D. F. Richardson presented a paper describing the Chattanooga hydroelectric power plant. The paper made clear the lay-out of the generating, transforming and transmitting apparatus. A discussion followed.

UNIVERSITY OF COLORADO

A meeting of the University of Colorado Branch was held on December 3. The speaker was Mr. B. C. J. Wheatlake, of the Denver office of the General Electric Company, who presented a paper on "Watt-hour Meters." He outlined the fundamental principles of operation of the watt-hour meters in ordinary use, and pointed out important features which are desirable in a good meter. Illustrative lantern slides were shown.

HIGHLAND PARK COLLEGE

The Highland Park College Branch held a meeting on December 10. Mr. Wallace Wick and Mr. D. C. Amo presented abstracts of the two recent Institute papers by Irving Langmuir and J. A. Orange, on nitrogen-filled tungsten lamps. A general discussion of the subject followed.

UNIVERSITY OF IOWA

The University of Iowa Branch held a meeting on November 25, 1913, when 25 new members were elected. The officers for the year are: president, J. H. Scanlon; vice-president, W. E. Schwob, and secretary, A. H. Ford.

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At the meeting of the Branch on December 16, Mr. J. H. Carmichael gave a talk on the building of a dam at Monticello, Iowa.

UNIVERSITY OF KENTUCKY

The University of Kentucky Branch held a meeting on December 8, when Messrs. T. D. Howard and E. B. Hayden read abstracts of the three papers presented at a recent Institute meeting, in New York, on the subject of electric lighting and motor-starting equipment for gasoline automobiles.

LEHIGH UNIVERSITY

The Lehigh University Branch held a meeting on December 19, at which two papers were presented by members of the senior class. "Electric Heaters" was the title of the paper by Mr. D. S. Aungst, describing the various ways of using electricity for heating purposes, and the applications in electric irons, glower radiators, electric furnaces, electric welding, and electric ignition of explosive gases.

Mr. J. R. Danner gave a talk on "The Engineering Corps of the United States Army." He described the surveying and construction work under the charge of army engineers and also the great variety of work done by the Signal Corps.

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### University of Maine

A meeting of the University of Maine Branch was held on January 8, when Mr. C. M. Kelley presented a paper on "Wireless Telegraphy."

### University of Missouri

The meeting of the University of Missouri Branch on December 8 was devoted to a discussion of the inspection trip to Chicago which had been made a short time previous by a number of members of the Branch. The speakers and their topics were as follows: Messrs. E. V. Gmeiner, the plant of the Chicago Sanitary District at Lockport; J. H. Spurgeon, the Fisk Street and Quarry Street plants of the Commonwealth Edison Company; H. M. Tickle, the Hawthorne Works of the Western Electric Company; E. W. Kellogg, the Universal Portland Cement works; P. W. Gumaer, the Gary steel works; and C. H. Kraft, the Keokuk power development. Other members of the Branch then took part in a general discussion.

### Montana State College

The Montana State College Branch held a meeting on November 21, when Mr. J. A. Thaler gave a talk on engineering education and the fields open to technical graduates.

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The next meeting of the Branch was held on December 18, when Dean Richter of the College of Engineering made an address on "The Control of Public Service Corporations." He explained the organization and duties of public service commissions, especially the duties of the engineering staff, and spoke of the success of the Wisconsin Commission. Dean Richter also told of the work already accomplished by the newly created Public Service Commission of Montana.

### Ohio Northern University

The Ohio Northern University Branch met on December 10, when three papers were presented.

Mr. R. H. Hart spoke on "Electrical Equipment for Gasolene Automobiles," and was followed by Mr. B. V. Yardley, who had for his subject "Practical Testing." Mr. Yardley, having worked in the testing department of the Westinghouse Electric and Manufacturing Company, was in a position to give a very practical talk. The last paper was one on "Steam Flow Meters," by Mr. Charles Buezis.

### Ohio State University

The Ohio State University Branch held a meeting on December 10. Officers were chosen to conduct the "electric show" to be given by the Branch, as follows: general manger, A. M. Lloyd; board of directors, L. R. Yeager, W. G. Hunter, G. A. Johnson and L. H. Brubaker; board of advisors, Professor F. C. Caldwell, R. M. Moody and J. E. Shepardson.

Mr. S. F. Swarr, 1911, now employed with the Westinghouse Electric and Manufacturing Company, gave a short talk on "Practical Application of Theory", bringing out several practical points that would be helpful to the present seniors.

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On December 17 the second banquet of the Branch was held at the Ohio Union. Mr. S. G. McMeen, president of the Columbus Railway and Light Company, and Mr. Edward Orton, Jr., dean of the Engineering Colleges, responded to toasts. Mr. McMeen told of some interesting events in connection with the formation of A. I. E. E. Sections in the Western States, and Mr. Orton spoke of a new branch of study just being experimented with in the department of ceramics, of which he is an instructor.

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At the meeting of the Branch on January 7, by-laws drawn up to govern the organizing of the "electrical show" were reported and adopted, and plans were discussed. The business manager said that more than 500 letters would be sent to electrical firms, inviting exhibits.

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Two papers were then presented: "Patent Office Drawing," by Mr. Lloyd W. Frost, and "Latest Electrical Equipment for Gasoline Automobiles," by Mr. H. Kurtz Randall.

### Oklahoma Agricultural and Mechanical College

The Oklahoma Agricultural and Mechanical College Branch held a meeting on January 8, when three Institute papers, *Operation of Transformers*, by Green, *Dynamo Electric Lighting for Motor Cars*, by Waller, and *Tungsten Lamps of High Efficiency*, by Langmuir and Orange, were presented by Messrs. R. A. Wood, Quentin Graham and O. C. Brown, respectively.

### University of Oklahoma

The seventh regular meeting of the University of Oklahoma was held on December 10. Mr. A. V. Hancock, head of the branch office of the General Electric Company at Oklahoma City, gave an illustrated talk on "Motor Construction." Mr. R. W. Stinson then presented a review of some articles in recent electrical periodicals.

### University of Oregon

The University of Oregon Branch held a meeting on December 9, 1913, when a paper on "Local Distributing Systems" was presented by Mr. F. C. Burke, superintendent of construction of the Oregon Power Company.

### Purdue University

At the meeting of the Purdue University Branch on November 11, 1913, Mr. Guy M. Laird, 1907, spoke on "Some Observations and Problems connected with the Supply of Electrical Energy to Mines and Smelters."

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The Purdue Branch held a meeting on November 25, when an address on "Some Phases of German Engineering" was made by Professor G. A. Young.

Professor Young was a member of the party of American engineers who were guests of the German engineers last summer. The trip included visits to the various universities, a complete inspection of their laboratories, which are the best equipped in the world, as well as visits to a number of large manufacturing establishments. One interesting characteristic of the German laboratory system at their universities is that each laboratory is equipped and used for but one engineering problem; or, it may be stated, that for every big engineering problem, whether it be electrical or mechanical or what not, there is a laboratory. The work in these may be and is carried on for several years, sometimes, before results are obtained.

Professor Young made a comparison of the method of administering the work there, which is chiefly by lectures in preference to recitations, as well as the relations existing between the teachers and students, the student life and work, with correspondng phases of American college work.

He also spoke of the engineering methods used by the Germans and compared them with those of our own country.

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At the meeting of the Branch on December 3, Mr. Thomas Steward, of the electrical engineering department of the university, spoke on the Big Creek hydroelectric development in California. The facts concerning this great power development were presented as Mr. Steward saw them, without reference to the technical and theoretical side.

The basin forming the water supply is located about seventy-five miles from Fresno, California. A railroad 56 miles in length and having a total of about 1200 curves in this distance, forms a means of communication with the outside world. In all, there will be four power houses, two of which have already been completed. The first is fed with water from the basin above by means of a tunnel which comes down the mountain side. From the first power station the tunnel conducts

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the water to the second, and thence similarly through the other two stations. When the system is completed, the water will run back into the river and be used for irrigation. All four stations have equal power equipment. A twelve-mile tunnel is being constructed to connect the third and fourth power houses with the San Joaquin river. This tunnel is to supply the last two stations in case of scarcity of water supply from the basin.

Mr. Steward gave many statistics to demonstrate the largeness of the undertaking. He illustrated his talk with a large number of pictures of the Big Creek development which he had obtained during a visit to the locality.

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At the meeting of the Branch on December 16, Mr. J. E. Scott, 1914, gave a general survey of the Keokuk power development as he saw it while employed there. He spoke of the various features that are of general interest, such as the method of providing for expansion and contraction of the dam, the ice-fenders which are built to protect the turbines from ice, the sea wall that protects the Chicago, Burlington and Quincy Railroad, and the locks and dry-docks. The power plant is centrally located in an active manufacturing district.

Mr. H. O. Murphy, 1915, described the installation in detail, giving a general description of the plant as well as of apparatus. He told of the method of distribution, of the various points supplied, the transmission system and its construction.

### Rensselaer Polytechnic Institute

The first meeting of the Rensselaer Polytechnic Institute Branch for the season was held on December 16 in the Sage Laboratory. Mr. W. J. Williams made an address on "The Value of Engineering Societies as a Means of Personal Advancement."

The address was followed by a discussion on the best method of conducting the meetings of the Branch. It was decided to postpone the election of officers until the February meeting.

### Stanford University

The annual Semester Banquet of the Stanford University Branch was held Thursday evening, December 11. The speaker of the evening was Mr. R. W. Van Norden, who gave a short description of the Lake Spaulding project of the Pacific Gas and Electric Company.

About 33 were present, including the newly elected members of the Branch.

### Texas Agricultural and Mechanical College

At the meeting of the Texas Agricultural and Mechanical College Branch on December 5, Mr. P. T. Groginski spoke on "Maintenance of Old and New Electric Railway Motors," and Mr. E. N. Hogue on "Electrical Measuring Instruments." Professor F. C. Bolton then gave an illustrated talk on modern electric railway motors and details of their construction, and also showed pictures of modern electric cars and locomotives.

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At the meeting of the Branch on December 19, two papers were presented: "Development of Gas Engines as Applied to Gas-Electric Plants," by Mr. S. R. Stribling, and "Development of Steam Turbines, Relative to Efficiency, Use, etc.", by Professor H. E. Smith.

### Washington University

The meeting of the Washington University Branch on December 16 was addressed by Mr. Pennell of the Southwestern Telephone and Telegraph Company, who gave an illustrated talk on the organization of the American Telephone and Telegraph Company.

### University of Washington

The December meeting of the University of Washington Branch of the Institute was held in the Good Roads Building, on the university campus, December 2.

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The following short papers were read: "The Development of the Arc Lamp," by Roy Coy; "The Development of the Incandescent Carbon Filament Lamp," by C. A. Stanwick; and "The Development of the Metallic Filament Lamp," by A. P. Newberry.

After the reading of these papers, there was a short discussion in which several students and members of the faculty took part.

WORCESTER POLYTECHNIC INSTITUTE

The meeting of the Worcester Polytechnic Institute Branch on December 12 was addressed by Mr. W. L. Towne, of the publicity department of the General Electric Company, of Schenectady, on "The Recent Developments in the Electric Railway Industry." The lecture was illustrated with colored lantern slides, the subjects being pieces of apparatus, new methods of construction, and new applications.

The attendance at this meeting was 100.

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The fourth regular meeting of the Branch for the season was held January 9, as a joint meeting with the W. P. I. Civil and Mechanical Engineering Societies.

Professor H. B. Smith gave a lecture on "Cosmopolitan Methods of Transportation." Professor Smith illustrated his talk with two hundred lantern slides selected from a large collection obtained during his travels in many parts of the world.

YALE UNIVERSITY

The Yale University Branch held its first meeting of the year in the recently completed Electrical Engineering Laboratory on October 29, 1913.

Mr. C. E. Clewell, of the faculty, gave an interesting talk on "Modern Lighting." He discussed the economical advantages of good factory lighting and the reasons for the great interest taken in the subject at the present day. Various types of lamps and lighting were displayed and their advantages and disadvantages discussed.

Professor Scott gave a short talk explaining the features of the new laboratory, following which the building was open to inspection by the visitors.

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A meeting of the Yale Branch was held on November 12, in the evening. Professor Scott introduced the speaker of the evening, Mr. Percy H. Thomas.

Mr. Thomas gave a broad and comprehensive talk on the subject of "High-Tension Transmission." He showed first the present and proposed development of transmission lines in the South, explaining the system by which this development is carried on. Many water power and steam plants are connected so as to feed into one continuous line, then the power used in the various towns and cities is tapped off from this common source. Mr. Thomas then discussed the problems connected with the designing and insulating of transmission lines, and the problems of keeping them in commission.

After discussing the mechanical side of the subject the electrical side was presented. This included an explanation of the charging current and corona loss incident to high-tension lines. Methods of overcoming the difficulties of operating a line which required too large a charging current were explained. Mr. Thomas also touched upon the effects of lightning and their prevention.

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## Personal

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MR. H. J. S. HEATHER has been appointed Professor of Electrotechnics in the School of Mines at Johannesburg, South Africa.

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MR. JAMES C. PRESTON has resigned his position as chief load dispatcher with the New York, New Haven and Hartford Railroad at Cos Cob, Conn., to take a course in agriculture at Iowa State College, preparatory to taking up the management of a 5000-acre farm belonging to the Estate of A. J. Preston at Castlewood, South Dakota.

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MR. ARTHUR I. TOTTEN has returned from Brazil and is now connected with the commercial section of the railway department of the General Electric Company. Mr. Totten had left that company August 1, 1912, and accepted a position as electrical engineer and assistant in charge of mechanical affairs of the Brazil Railway, with headquarters at Sao Paulo, Brazil.

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MR. E. J. PIETZCKER, formerly southwestern sales manager, at St. Louis, of the Standard Underground Cable Company, has been made western and southwestern sales manager, in charge of the Chicago and St. Louis offices of the company, covering the Mississippi River basin. Mr. Pietzcker's connection with various branches of the wire and cable industry began prior to 1890, with the Washburn and Moen Manufacturing Company. In 1902 he joined the forces of the Standard Underground Cable Company, under Mr. J. R. Wiley, western sales manager, at Chicago. The death of Mr. Wiley, who had been western manager for the company for nearly twenty years, occurred last fall.

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MR. W. R. GARTON has resigned as vice-president and general manager of the Lord Manufacturing Company, Brooklyn, N. Y. Mr. Garton has been active in the electrical field for many years and is well-known. He began in the construction and operation of telephone, electric light and railway properties, and has given much time to the supply and manufacturing business. Mr. Garton is an Associate of the American Institute of Electrical Engineers and a member of the American Electric Railway Association, the New York Railway Club, the Keystone Electric Railway Club, the New England Street Railway Club and the New York Electric Railway Association. His temporary address will be 851 East Nineteenth Street, Brooklyn, N. Y.

## Obituary

EUGENE ROMIG, Assoc. A. I. E. E., assistant electrical engineer of the U. S. Electrical Manufacturing Company, Los Angeles, California, died at his home in Los Angeles on December 30, 1913. Mr. Romig was born September 10, 1892, and received his technical training at the University of Southern California. He was elected an Associate of the Institute on October 10, 1913.

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WILLIAM DENNIS MARKS, Mem. A. I. E. E., consulting engineer, and formerly Whitney professor of dynamic engineering in the University of Pennsylvania, died in the Champlain Valley Hospital at Plattsburg, N. Y., on January 7, 1914. Professor Marks was born in St. Louis, February 26, 1849. He was graduated from Yale in 1870 with the degree of Ph. B., and later received the degree of C. E. from the same college. After an experience of practical engineering work in connection with railways and gas and iron works, he was appointed instructor in mechanical engineering at Lehigh University, and the following year went to the University of Pennsylvania. In 1884 he was superintendent of the International Electrical Exhibition of the Franklin Institute, and later became engineer and president of the then Edison Electric Light Company of Philadelphia. He was elected an Associate of the American Institute of Electrical Engineers on February 7, 1888, and on May 1 of the same year was transferred to the grade of Member. Professor Marks had a consulting engineering office in New York, but for some time past had been living in Westport, N. Y. He was an honorary life member of the Franklin Institute and a member of the American Philosophical Society.

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RICHARD NOTT DYER, Mem. A.I.E.E., a prominent patent lawyer, senior member of the firm of Dyer, Dyer and

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Taylor, of New York, died at his home in East Orange, N. J., on January 13, 1914. Mr. Dyer was born in Calais, Maine, fifty-six years ago. He was graduated from the Columbian University, Washington, D. C., and was admitted to the bar in Chicago in 1879. Two years later he went to Menlo Park, N. J., as patent attorney for Mr. Thomas A. Edison. He represented Mr. Edison in the fight to sustain his rights as inventor of the incandescent lamp, which was carried to the United States Supreme Court. In this case he obtained numerous decisions which have been quoted ever since in patent cases. Mr. Dyer also prepared the Edison patents on the phonograph and kinetoscope and carried these cases through the courts. Later he became counsel for the Sprague Electric Company and for several years had charge of the patent work of the General Electric Company. He was elected an Associate of the Institute on July 12, 1887, and a Member on September 6 of the same year.

## Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

Association of Municipal and Sanitary Engineers and Surveyors Proceedings, vol. I-III. London, 1875-77. (Purchase.)

Canadian Electrical Association. Proceedings 22d Annual Convention, 1912. Toronto, 1912. (Exchange.)

College of Science, Imperial University of Tokyo: Journal. General Index to vols. 1-25, 1887-1908. Toyko, 1913. (Exchange.)

Electric Arc Phenomena. By Ewald Rasch. Translated from the German by K. Tornberg. New York, D. Van Nostrand Co., 1913. (Gift of Publishers.) Price $2.00 net.

A treatment of arc phenomena in the light of recent electrical theory. The last chapter treats of the efficiency of the various commercial forms of arc lamps. W. P. C.

Elektrizitätszähler fur Gleich-Wechsel und Drehstrom, deren Theorie, Beschreibung und Eichung. By H. W. L. Bruckmann, Leipzig, 1914. (Purchase.)

Growing Crops and Plants by Electricity. By E. C. Dudgeon, London, n.d. (Purchase.)

The William J. Hammer Historical Collection of Incandescent Lamps. By William J. Hammer. (Reprinted from the Transactions of the New York Electrical Society, No. 4, 1913.) (Gift of author.)

Management of Public Electric Supply Undertakings. By A. H. Seabrook. New York, 1913. (Purchase.)

Manufacture of Reinforced Concrete Poles, Piles and Pipe without the use of forms. By R. M. Jones. Denver, n.d. (Gift of R. M. Jones.)

New York State College of Forestry. Wood-Using Industries of New York. Albany, 1913. (Gift of U. S. Department of Agriculture.)

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——First Annual Industrial Directory of New York State, 1912. Albany, 1913. (Gift of New York State Department of Labor.)

Philadelphia. Transit Commissioner. Report, 1913, vol. I-II. Philadelphia, 1913. (Gift of Messrs. Ford, Bacon and Davis.)

Polytechnic Institute of Brooklyn. Catalogue of the College of Engineering. 1914-15. (Gift of Polytechnic Institute.)

Practical Uses of the Wave Meter in Wireless Telegraphy. By J. O. Mauborgne. New York, McGraw-Hill Book Co., 1913. (Purchase.)

Present Insurance Situation from an Insurance Superintendent's Viewpoint. An address by W. T. Emmet. n.p. 1913. (Gift of Insurance Society of New York.)

Re-arrangement and development of the steam railroad terminals of the city of Chicago, Report. By B. J. Arnold. Chicago, 1913. (Gift of author.)

Switchboards, switching, protective apparatus. By C. C. Adams. Chicago, American School of Correspondence, 1914. (Gift of publisher.)

A well-illustrated practical manual. The author is switchboard engineer of the General Electric Company. W. P. C.

Tafeln zur astronomischen Ortsbestimmung. By Arnold Kohlschutter. (Luftfahrt und Wissenschaft, pt. 7.) Berlin, 1913. (Purchase.)

Technische Schwingungslehre. By Wilhelm Hort. Berlin, 1910. (Purchase.)

Die Theorie Moderner Hochspannungsanlagen. By A. Buch. Munchen, 1913. (Purchase.)

Versuche an Doppeldeckern zur Bestimmung ihrer Eigengeschwindigkeit und Flugwinkel. By Wilhelm Hoff (Luftfahrt und Wissenschaft, pt. 6.) Berlin, 1913. (Purchase.)

GIFT OF FRANCIS B. CROCKER.

Herzog et. al. vs. New York Telephone Company. Briefs for complainants and defendants. 1908.

——Patent for signaling system. Complainant's Record, 1903-07.

——Defendant's Record, vol. 1-2, 1904-07.

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Thomson-Houston Electric Company and General Electric Company vs. Traction Equipment Company. On Whitman Patent and short and case patents for car Rheostats. 1903-08.

Union Carbide Company vs. American Carbide Company. On Process patent No. 563,527. Brief for Defendant. Complainant's Record, Defendant's Record. N. Y., 1909.

TRADE CATALOGUES.

Allgemeine Elektricitäts Gesellschaft. Berlin, Germany. Nitralampe Halbwatt pro Kerze.

Grosse dampfturbopumpen für Wasserwerke aller Art. (1012, 1013, 1014) 1913.

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Gekapselter Amperestundenzähler. 24 pp. 1913.

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Allis-Chalmers Manufacturing Co. Milwaukee, Wis. Polyphase induction motors. (No. 4005). Nov., 1913.

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——Bull. A4185. Single-phase induction motors, type KS. Oct. 1913.

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Westinghouse Electric & Manufacturing Co. East Pittsburgh, Pa. Circular 1104. Westinghouse portable meters for alternating and direct current.

——1205. Carbon circuit breakers. July, 1913.

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Carnotite. The principal source of radium. By T. F. V. Curran. New York, 1913. (Gift of Curran & Hudson.)

Historic Priorities in Lynn. An address given at the dedication of the Society House, Lynn Historical Society, Oct. 9, 1913. By C. J. H. Woodbury. Lynn, 1913. (Gift of C. J. H. Woodbury.)

Mercantile Marine Atlas. Edited by George Philip. Ed. 4. New York, 1913. (Purchase.)

National Tube Company. Book of Standards. Pittsburgh, 1913. (Gift of National Tube Co.)

Relation of West Virginia Coals to the Panama Canal. Address of Ex-Governor W. A. MacCorkle before the West Virginia Coal Mining Institute, Dec. 8, 1913. n.p. n.d. (Gift of West Virginia Coal Mining Institute.)

Street Directory of the Prinicpal Cities of the United States, embracing letter-carrier offices established to April 30, 1908. Ed. 5. Washington, 1908. (Purchase.)

Test of a 40-foot Reinforced Concrete Highway Bridge. By D. A. Abrams. (Gift of author.)

World's Fair Bulletin. Louisiana Purchase Exposition, 1904. (Gift of St. Louis Public Library.)

GIFT OF INTERNATIONAL SAFETY EXHIBITION, 1913.

Educational and other employee relations including outline of educational courses for 1913-14. New York Edison Company, 1913.

A Nation's Neglect. By M. A. Low.

Resuscitation from electric shock. By C. A. Lauffer.

Safety, Vol. 1, No. 3. August 1913.

Stop, look, listen. By F. V. Whiting.

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| *WILLIAM A. ANTHONY, 1890-91. | SCHUYLER SKAATS WHEELER, 1905-6. |
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| FRANK JULIAN SPRAGUE, 1892-3. | HENRY G. STOTT, 1907-8. |
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| LOUIS DUNCAN, 1895-6-7. | LEWIS B. STILLWELL, 1909-10. |
| FRANCIS BACON CROCKER, 1897-8. | DUGALD C. JACKSON, 1910-11. |
| A. E. KENNELLY, 1898-1900. | GANO DUNN, 1911-12. |
| | RALPH D. MERSHON, 1912-13. |

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Revised to February 1, 1914.

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| **Los Angeles**.....May 19, '08 | E. R. Northmore. | C. G. Pyle, 914 Hibernian Bldg., Los Angeles, Cal. |
| **Lynn**.....Aug. 22, '11 | E. R. Berry. | J. A. McManus, Jr., General Electric Co., Lynn, Mass. |
| **Madison**.....Jan. 8, '09 | Edward Bennett. | F. A. Kartak, Univ. of Wisconsin, Madison, Wis. |
| **Mexico**.....Dec. 13, '07 | Norman Rowe. | James Carson, Mexican Light and Power Company, Mexico City, Mexico. |
| **Milwaukee**.....Feb. 11, '10 | L. E. Bogen. | L. P. Coulter, 2500 Chestnut Street, Milwaukee, Wis. |
| **Minnesota**.....Apr. 7, '02 | W. T. Ryan. | Fred G. Dustin, 9 South Fifth St., Minneapolis, Minn. |
| **Panama**.....Oct. 10, '13 | Edward Schildhauer. | W. R. McCann, Isthmian Canal Commission, Culebra, Canal Zone |
| **Philadelphia**.....Feb. 18, '03 | A. R. Cheyney. | H. F. Sanville, 1326 Chestnut St., Philadelphia, Pa. |
| **Pittsburgh**.....Oct. 13, '02 | A. M. Dudley. | E. R. Spencer, 814 Frick Building, Pittsburgh, Pa. |
| **Pittsfield**.....Mar. 25, '04 | J. J. Frank. | G. W. Wade, General Electric Company, Pittsfield, Mass. |
| **Portland, Ore.**.....May 18, '09 | G. P. Nock. | R. F. Monges, G. E. Co., Electric Building, Portland, Ore. |
| **St. Louis**.....Jan. 14, '03 | F. J. Bullivant. | A. McR. Harrelson, Emerson Electric Mfg. Co., St. Louis, Mo. |
| **San Francisco**...Dec. 23, '04 | A. H. Griswold. | A. G. Jones, 819 Rialto Building, San Francisco, Cal. |
| **Schenectady**.....Jan. 26, '03 | George H. Hill. | John R. Hewett, Gen. Elec. Co., Schenectady, N. Y. |
| **Seattle**.....Jan. 19, '04 | S. C. Lindsay. | E. A. Loew, University of Washington, Seattle, Wash. |
| **Spokane**.....Feb. 14, '13 | J. B. Fisken. | H. B. Peirce, Box 1436, Spokane, Wash. |
| **Toledo**.....June 3, '07 | George E. Kirk. | Max Neuber, Cohen, Freidlander & Martin, Toledo, O. |
| **Toronto**.....Sept. 30, '03 | D. H. McDougall. | H. T. Case, Continental Life Bldg., Toronto, Ont. |
| **Urbana**.....Nov. 25, '02 | Morgan Brooks. | I. W. Fisk, University of Illinois, Urbana, Ill. |
| **Vancouver**.....Aug. 22, '11 | E. M. Breed. | L. G. Robinson, 1003 Holden Building, Vancouver, B. C. |
| **Washington, D.C.**..Apr. 9, '03 | H. C. Eddy. | C. B. Mirick, 1302 N. Street, N.W., Washington, D. C. |

Total, 30.

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# LIST OF BRANCHES

Revised to February 1, 1914.

| Name and when Organized. | Chairman | Secretary |
|---|---|---|
| **Agricultural and Mechanical College of Texas**.....Nov. 12, '09 | D. B. Pickens. | E. C. Rack, A. & M. College, College Station, Tex. |
| **Arkansas, Univ. of**.....Mar. 25, '04 | S. S. McGill. | M. B. Roys, Univ. of Arkansas, Fayetteville, Ark. |
| **Armour Institute**.....Feb. 26, '04 | E. L. Nelson. | T. C. Bolton, Armour Inst. Tech., Chicago, Ill. |
| **Bucknell University**.....May 17,'10 | P. O. Schnure. | J. M. Hillman, Bucknell University, Lewisburg, Pa. |
| **California, Univ. of**.....Feb. 9, '12 | Charles Z. Yost. | L. E. Rushton, University of California, Berkeley, Cal. |
| **Cincinnati, Univ. of**.....Apr. 10, '08 | John H. Stewart. | J. S. Bishop. 2345 Kemper Lane, Cincinnati, Ohio. |
| **Clemson Agricultural College**.....Nov. 8, '12 | F. J. Jervey. | F. H. McDonald, Clemson College, S. C. |
| **Colorado State Agricultural College**.....Feb. 11, '10 | L. M. Klinefelter. | R. K. Havighorst. Colorado State Agricultural College, Fort Collins, Colo. |
| **Colorado, Univ. of**.....Dec. 16, 04 | L. E. Sweitzer. | Frank A. Redding, University of Colorado, Boulder, Colo. |
| **Highland Park College**..Oct. 11, '12 | E. B. Williams. | Ralph R. Chatterton, Highland Park College, Des Moines, Iowa. |
| **Iowa State College**.....Apr. 15, '03 | Earle G. Nichols. | F. A. Robbins, Iowa State College, Ames, Iowa. |
| **Iowa, Univ. of**.....May. 18, '09 | J. H. Scanlon. | A. H. Ford, University of Iowa, Iowa City, Ia. |
| **Kansas State Agr. Col.**..Jan. 10, '08 | C. A. Leech. | W. C. Lane, Kansas State Agric. Col., Manhattan, Kan. |
| **Kansas, Univ. of**.....Mar. 18, '08 | H. C. Hansen. | L. M. Bocker, Univ. of Kansas, Lawrence, Kansas. |
| **Kentucky State Univ. of**.Oct. 14, '10 | H. B. Hedges. | H. Tyler Watts, 315 East Maxwell Street, Lexington, Ky. |
| **Lafayette College**.....Apr. 5, '12 | G. P. Ellis. | V. A. Davison, Lafayette College, Easton, Pa. |
| **Lehigh University**.....Oct. 15, '02 | W. B. Todd. | G. Forster, Lehigh University, S. Bethlehem, Pa. |
| **Lewis Institute**.....Nov. 8, '07 | Ralph Kilner. | A. H. Fensholt, Lewis Institute, Chicago, Ill. |
| **Maine, Univ. of**.....Dec. 26, '06 | C. M. Kelley. | E. L. Getchell, University of Maine, Orono, Maine. |
| **Michigan, Univ. of**.....Mar. 25, '04 | P. H. Evans. | W. B. Kopfer, 616 Church Street, Ann Arbor, Mich. |
| **Missouri, Univ. of**.....Jan. 10, '03 | H. B. Shaw. | E. W. Kellogg, 9 Engineering Building, Columbia, Mo. |
| **Montana State Col**.....May 21, '07 | Max W. Kenck. | J. A. Thaler, Montana State College, Bozeman, Mont. |

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## LIST OF BRANCHES—Continued

| Name and when Organized | Chairman | Secretary |
|---|---|---|
| **Nebraska, Univ. of**.....Apr. 10, '08 | Olin J. Ferguson. | V. L. Hollister, Station A, Lincoln, Nebraska |
| **New Hampshire Col.**.....Feb. 19, '09 | | |
| **North Carolina Col. of Agr. and Mech. Arts**.....Feb. 11, '10 | Wm. H. Browne, Jr. | James Fontaine, West Raleigh, N. C. |
| **Ohio Northern Univ.**.....Feb. 9, '12 | George E. Boesger | Harry Restofski, Ohio Northern University, Ada, Ohio. |
| **Ohio State Univ.**.....Dec. 20, '02 | L. R. Yeager. | John M. Strait, Ohio State Univ., Columbus, Ohio. |
| **Oklahoma Agricultural and Mech. Col.**.....Oct. 13, '11 | A. P. Little. | Quentin Graham, 416 Hester Street, Stillwater, Okla. |
| **Oklahoma, Univ. of**.....Oct. 11, '12 | R. D. Evans. | L. J. Hibbard, Univ. of Oklahoma, Norman, Okla. |
| **Oregon Agr. Col.**.....Mar. 24, '08 | A. O. Manigold. | I. L. Olmstead, Oregon Agric. Col., Corvallis, Ore. |
| **Oregon, Univ. of**.....Nov. 11, '10 | C. R. Reid. | C. H. Van Duyn, Univ. of Oregon, Eugene, Oregon. |
| **Penn State College**.....Dec. 20, '02 | T. A. Jones. | A. D. Shultz, State College, Pa. |
| **Purdue Univ.**.....Jan. 26, '03 | C. F. Harding. | A. N. Topping, Purdue University, Lafayette, Ind. |
| **Rensselaer Poly. Inst.**....Nov. 12, '09 | E. D. N. Schulte. | W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y. |
| **Rose Polytechnic Inst.**....Nov. 10, '11 | Charles F. Harris. | Claude A. Lyon, 1331 Liberty Avenue, Terre Haute, Ind. |
| **Rhode Island State Col.**..Mar. 14, '13 | Harry Webb. | P. M. Randall, Rhode Island State College, Kingston, R. I. |
| **Stanford Univ.**.....Dec. 13, '07 | G. O. Wilson. | L. M. Bussert, Stanford University, Cal. |
| **Syracuse Univ.**.....Feb. 24, '05 | W. P. Graham. | R. A. Porter, Syracuse University, Syracuse, N. Y. |
| **Texas, Univ. of**.....Feb. 14, '08 | Joseph W. Ramsey. | J. A. Correll. University of Texas, Austin, Tex. |
| **Throop College of Technology**.....Oct. 14, '10 | Ray Gerhart. | R. W. Parkinson, Throop Poly. Institute, Pasadena, Cal. |
| **Vermont, Univ. of**.....Nov. 11, '10 | | |
| **Virginia, Univ. of**.....Feb. 9, '12 | Walter S. Rodman | Henry Woodman Clark, A. X. P. House, University, Virginia. |
| **Wash., State Col. of**....Dec. 13, '07 | M. K. Akers. | H. V. Carpenter, State Coll. of Wash., Pullman, Wash. |
| **Washington Univ.**.....Feb. 6, '04 | R. D. Duncan, Jr. | C. C. Hardy, Washington University, St. Louis, Mo. |
| **Washington, Univ. of**...Dec. 13, '12 | A. P. Newbury. | Charles A. Stanwick, Univ. of Washington, Seattle, Wash. |
| **Worcester Poly. Inst.**.....Mar. 25, '04 | W. C. Blanchard. | Harry B. Lindsay, Worcester Poly. Inst., Worcester, Mass. |
| **Yale University**.....Oct. 03, 10 | R. G. Warner. | K. B. Jones, 136 Vanderbilt-Scientific, New Haven, Conn. |

Total, 47.

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# SECTION II

# PROCEEDINGS

of the

# American Institute

of

# Electrical Engineers

Papers, Discussions and Reports

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**PROCEEDINGS**

OF THE

**American Institute**

OF

**Electrical Engineers.**

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol. XXXIII **March, 1914** No. 3

## Midwinter Convention

As this issue of the PROCEEDINGS goes to press, the sessions of the Second Midwinter Convention are being held in the Engineering Societies Building, New York, under the auspices of the Electric Power Committee of the Institute. A complete report of the convention will appear in the April PROCEEDINGS.

## Coming A. I. E. E. Meetings

### New York, March 13, 1914

The 292d meeting of the A. I. E. E. will be held in the auditorium of the Engineering Societies Building, New York, March 13, 1914. The meeting will be under the auspices of the Telegraphy and Telephony Committee, and the Institute of Radio Engineers will participate with the A. I. E. E. in this meeting.

Three papers will be presented, two of which are *A Comparison of the Telegraph with the Telephone as a Means of Communication in Steam Railway Operation*, by Mr. M. H. Clapp, superintendent of the telegraph department of the Northern Pacific Railway Company, and *Traffic Studies in Automatic Switchboard Telephone Systems* by W. Lee Campbell, general superintendent of the Automatic Electric Company, Chicago; both of these papers are printed elsewhere in this issue of the PROCEEDINGS. Under the auspices of the Institute of Radio Engineers a paper will be presented on "*The Goldschmidt System of Radiotelegraphy*" by Mr. E. E. Mayer; this paper will be illustrated by lantern slides.

At the close of the technical session the meeting will adjourn to the Institute rooms on the 10th floor, where a smoker will be held and light refreshments served.

### Pittsburgh, April 9-10, 1914

The 293d meeting of the A. I. E. E. will be held in Pittsburgh, Pa., April 9 and 10, 1914. The meeting will be under the auspices of the Committee on Use of Electricity in Mines, and the following papers will be presented: "*Mine Duty Controllers*" by H. P. Reed; "*Self-Contained Portable Electric Lamps*" by H. O. Swoboda; *Mine Substations, Part I*, "*The Construction and Operation of Mine Substations*" by H. Booker; *Part II*, "*Motor-Generator Sets vs. Synchronous Converters as Applied to Mine Work*", by W. M. Hoen; and "*The Development of the Electric Mine Locomotive*" by G. M. Eaton. There will also be a general discussion on rules for electrical installations in mines, and the following rules will be used as a basis of discussion—(a) German Rules, (b) English Rules, (c) Bureau of Standards Rules, (d) American Mining Congress Rules, (e) Pennsylvania Mining Law, Electrical Section.

The complete program of the Pittsburgh meeting will be published in the April issue of the PROCEEDINGS.

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**Washington, D. C., April 24-25, 1914**

The 294th meeting of the Institute will be held in Washington, D. C., April 24-25, 1914. This will be a joint meeting under the auspices of the Electrophysics Committee and the Washington Section of the A.I.E.E., and the American Physical Society. There will be five papers presented on behalf of the A.I.E.E., as follows: "*A Theory of Corona*" by Bergen Davis, "*Some Investigations of Lightning Protection for Buildings*" by T. M. De Blois, "*A Milliampere Current Transformer*" by Edward Bennett, "*Some Simple Examples of Transmission Line Surges*" by W. S. Franklin, and "*Solenoids*" by C. R. Underhill.

The program is as follows—Friday, April 24, morning: technical session, Physical Society and the A. I. E. E., conducted by the Physical Society. Afternoon: inspection of buildings of the Bureau of Standards and exhibition of laboratory equipment and methods. In addition to the apparatus of the Bureau there will be an exhibit of recently developed lecture, laboratory and research apparatus supplied by manufacturers, dealers, universities, and private individuals. This exhibit is under the auspices of the American Physical Society and will be similar to the successful annual exhibits of the London and French Physical Societies. Evening: joint technical session of the Physical Society and the A. I. E. E., conducted by the Electrophysics Committee, to be followed by a smoker.

Saturday, April 25, morning: technical session of the Physical Society and the A. I. E. E., conducted by Physical Society. Afternoon: visits to points of interest in Washington. Parties to be conducted by the Washington Section of the A. I. E. E.

The details of this program are tentative and subject to modifications.

**New York, May 19, 1914**

The 295th meeting of the A. I. E. E. will be held in the auditorium of the Engineering Societies Building, New York, May 19, 1914. This will be the regular annual business meeting of the Institute at which the announcement of the election of officers for the ensuing year will be made. Following the business meeting there will be a technical session under the auspices of the Committee on Electricity in Marine Work. The papers to be presented at this meeting will be announced in a future issue of the PROCEEDINGS.

**Pittsfield, May 29, 1914**

The 296th meeting of the A. I. E. E. will be held at Pittsfield, Mass., May 29, 1914. The headquarters of the meeting will be at the Maplewood Hotel, Pittsfield, and the meeting will be under the auspices of the Pittsfield Section of the Institute. The principal subject of the meeting will be "*Relative Advantages of Y and Delta Connections*", and all the papers presented will have some bearing on this general subject. The following papers have been promised for this meeting: "*Grounding of Transmission Lines*", by C. P. Steinmetz; "*Experience with Line Transformers*", by D. W. Roper; "*A Study of Some Three-Phase Systems*", by C. L. Fortescue; "*Relative Merits of Y and Delta Connections for Generators*", by T. S. Eden; "*Conditions under which Harmonics are Produced*", by Mr. Clinker; and "*Stresses in Three-Phase Operation*", by L. F. Blume.

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**Annual Convention**
**June 22-26, 1914**

The 31st Annual Convention of the A. I. E. E. will be held in Detroit, Michigan, June 22-26, 1914. Convention headquarters will be at the Hotel Cadillac. The Meetings and Papers Committee requests that authors desiring to present papers at this convention will notify the committee to this effect promptly and submit their manuscripts at Institute headquarters on or before April 1, 1914.

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### 1914 Year Book

The Institute Year Book for 1914 has been published and may be obtained free of charge by any member upon application to the Secretary, 33 West 39th Street, New York, by mail or otherwise. The book, which is published primarily for distribution to non-members in connection with the work of the Membership Committee, contains the constitution, by-laws, lists of committees and members, and considerable other general information relating to the activities of the Institute.

### Cleveland Section Meeting

The March meeting of the Cleveland Section of the A. I. E. E. will be held on Monday, March 23, in the electrical laboratory of the Case School of Applied Science, Cleveland. The paper of the evening will be presented by Mr. L. P. Crecelius and is entitled *Sixty-Cycle Synchronous Converters*. The paper is printed elsewhere in this issue.

### Opening of the 38th Street Station, Sixth Avenue Elevated Railway

The attention of members of the Institute and all who make use of the facilities of the Engineering Societies Building in New York, is called to the fact that a new station has recently been opened at 38th Street on the Sixth Avenue elevated railway line of the Interborough Rapid Transit Company. This new station increases the accessibility of the Institute headquarters.

### Progress Report of Joint Committee on Inductive Interference

The Joint Committee on Inductive Interference, authorized by the Railroad Commission of the State of California to make investigations into inductive disturbances in telephone and telegraph circuits, as a basis for future regulations of the commission, has issued a second progress report, covering the work done up to December 16, 1913, on the study of two parallels (20 miles and 8 miles) of high-tension three-phase transmission lines and telegraph and telephone circuits in California. Some of the general results and conclusions indicated by a study of the engineers' reports are given. Until such time as the Joint Committee is prepared to make definite recommendations to the Railroad Commission it will indicate only in a general way the results of its investigation.

This second progress report has been published in full in *Western Engineering*, February, 1914, page 96, and in the *Journal of Electricity, Power and Gas*, Vol. XXXII, No. 5, page 101 (January 31, 1914). An abstract was published in the *Electrical World*, Vol. 63, No. 6, page 300 (February 7, 1914), and certain extracts from the report were given verbatim in the *Electric Railway Journal*, Vol. 43, No. 6, page 313 (February 7, 1914).

### Recommended for Transfer, February 17, 1914

The Board of Examiners, at its regular monthly meeting on February 17, 1914, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO THE GRADE OF FELLOW

PENDER, HAROLD, Professor of Electrical Engineering, Massachusetts Institute of Technology, Boston, Mass.

TO THE GRADE OF MEMBER

BOLTON, FRANK C., Professor of Electrical Engineering, A. & M. College of Texas, College Station, Texas.

CREAGH, EDRIC C., Electrical Engineer, Hydro-Electric Power & Metallurgical Co., Ltd., Hobart, Tasmania.

MAXWELL, J. M. S., Electrical Engineer, Glasgow, Scotland.

WARREN, J. F., Engineer in charge, Waipori Falls Power Station, Dunedin, New Zealand.

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WINETRAUB, ADOLPH I. M., Resident Engineer, General Electric Co., Havana, Cuba.

## Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before March 30, 1914.

Albrecht, A. H., St. Louis, Mo.
Alexander, W. N., Council Bluffs, Ia.
Andrew, W. M., Toronto, Ontario.
Applegate, K. P., Hartford, Conn.
Arthur, M. W., Cincinnati, Ohio.
Bagley, R. C., Chicago, Ill.
Ball, W. J., Moline, Ill.
Barnard, J. A., Philadelphia, Pa.
Bentley, R. O., Hackensack, N. J.
Berry, R. M., Bedford City, Va.
Braga, E. de A. (Fellow), Rio de Janeiro, Brazil
Bullard, L. H., Gatun, C. Z.
Bunn, D. M., Bluefield, W. Va.
Clark, W. C., Kellogg, Idaho
Clendenin, J. C.,(Member),Lynn,Mass.
Coates, W. A., (Member),Toronto, Ont.
Connon, C. A., Bodfish, Cal.
Cornell, G. B., Jr., Yonkers, N. Y.
Cory, F. C., Toledo, Ohio
Crampton, F. F., Toledo, Ohio
Davies, W. P., Schenectady, N. Y.
Deacon, R. W., Sudbury, Ont.
Deel, G. R., Corozal, C. Z.
Falcke, J., Rhodesia, S. Africa.
Fitzpatrick, W. L., Corozal, C. Z.
Force, H. H., New Britain, Conn.
Furlong, W. R., Washington, D. C.
Gill, M. F., Dallas, Texas.
Gillett, O. G., New York, N. Y.
Goldman, O. B., Portland, Ore.
Graham, F. A., Kansas City, Mo.
Hamilton, J. T., Van Nest, N. Y.
Harrington, L. J., Chicago, Ill.
Hood, S. B., (Member), Toronto, Ont.
Hummel, P. B., Jamaica, L. I., N. Y.
Lapp, J. S., Victor, N. Y.
Lewis, R. H., Brainerd, Minn.
Macintosh, J. M., Rio de Janeiro,Brazil.
Meyer, A. A., Detroit, Mich.
Nellis, W. H., Corozal, C. Z.
Norton, K. E., Coldwater, Mich.
Olsen, B., Spokane, Wash.
O'Neill, C. F., New York, N. Y.
Paget, J. H., Vancouver, B. C.
Palmblade, R. F., Peoria, Ill.
Patterson, J. G., Boston, Mass.
Perry, W. J., Corozal, C. Z.
Place, A. G., Youngstown, Ohio
Powell, W. T., Chicago, Ill.
Ramm, T. D., St. Paul, Minn.
Rice, L. E., Scranton, Pa.
Russell, F., Spokane, Wash.
Sato, Y., Tokyo, Japan.
Scholl, W. E., Wallace, Idaho.
Scott, H. C., Easthampton, Mass.
Shaw, T. (Member), New York, N. Y.
Simmons, W. B., Newark, N. J.
Stacy, W. K., Spokane, Wash.
Stange, H. D., Chicago, Ill.
Stegmaier, C. H., Indianapolis, Ind.
Summers, O. B., Birmingham, Ala.
Suttor, J. B., Jr., Sydney, Australia.
Thompson, R. E., Boston, Mass.
Thompson, R. M., Toronto, Ont.
Uggla, W. R., Finspong, Sweden.
Webber, E. M., Chicago, Ill.
Whiting, H. S., (Member), Culebra,C.Z.
Woodhouse, G. E., Toronto, Ont.
Worthington, E. H., Chicago, Ill.
Wyckoff, H. J., Detroit, Mich.

## United Engineering Society Treasurer's Report

*To the Board of Trustees,*
*United Engineering Society.*

I beg to submit herewith the report of your Treasurer as of December 31, 1913:

### I. FINANCES

The balance sheet submitted herewith shows the physical property of the United Engineering Society, over and above the value of the building and the equity in the land, to consist of building equipment of a value of $27,357.16, furniture

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and fixtures $5,795.46, and library books $329.07.

There was added to the furniture and fixtures account during the year 1913 an amount representing an expenditure of $390.96, the principal items of which are: drapery and hangings, alcove room, $150.66; asbestos booth for moving pictures, $70; filing cabinet, $50.70; and 3 perforated rubber mats, $48. In accordance with a resolution of the Board of Trustees, 10 per cent depreciation was charged off this account for the year 1913.

The principal of the mortgage on the land held by Andrew Carnegie, Esq., amounting originally to $540,000, has been reduced by payments from the Land and Building Funds of the Founder Societies to $88,000. Payment of $40,000 was made during the year by the American Institute of Mining Engineers. The present balances due from the societies are as follows: American Institute of Electrical Engineers, $54,000, and American Institute of Mining Engineers $34,000. The American Society of Mechanical Engineers has paid the full amount of its indebtedness.

The gross operating expenses for the year 1913 were $38,981.54 as compared with $47,602.71 for the preceding year, showing a decrease of $8,621.17. During the year 1913 there has been very little expenditure of an unusual nature. The following are the principal items:

| | |
|---|---|
| Storm doors—ground floor | $220.00 |
| 4 Metal doors " " | 200.00 |
| Additions to heating and ventilating | 250.00 |
| 2 Bookshelf cases (reimbursed by A. I. E. E.) | 930.00 |
| Painting interior | 239.45 |
| Taking down partitions Room 703, refitting in Room 901 | 245.75 |
| Removing partition 11th floor (reimbursed by A. S. M. E.) | 64.78 |
| 500 Copies of By-Laws | 156.14 |

In accordance with a resolution of the Board at a meeting held on January 23, 1913, an appropriation of $5,000 was made out of the surplus for the year 1912, and of this amount $4,943.75 was invested in $5,000 New York City 4½ per cent Corporate Stock, repayable 1962 at 98 13/16, as an addition to the Contingency and Renewal Fund, as provided for in the Founders' Agreement, bringing the amount of said fund to $29,963.75.

The assessments paid for the year by the founder societies, each occupying an entire floor, were $3,375, representing, as last year, a total expenditure by each founder society, including interest on its full principal of mortgage on land, of $10,575, reduced in each case to the extent the society may have paid off part or all of its mortgage share. The Associate Societies are assessed approximately $10,000 for equivalent privileges, which shows that the Founder Societies still meet a little more than their proportion of the carrying charges for equivalent office space occupancy in the building.

## II. Building

*Equipment*: The real estate equipment account during the year 1913 has been increased to an extent of $732.44, expended mainly in changes to north side of foyer on ground floor, sliding doors to create new room and architect's services in connection therewith, also bookstacks on the 12th floor.

*Office Occupancy*: There was on January 1, 1914, no unoccupied floor space (devoted to office space) in the building. There are, however, two rooms on the 12th floor used during the past year for storage purposes from which no income has been received. There are now sixteen associate societies occupying office space in the building.

*Meetings or Lectures*: The record of the number of times the rooms were used during 1913 for meetings or lectures (not for office occupancy) is shown in the accompanying table.

During the year 1913 the facilities of the building were enjoyed by 56 societies holding a total of 309 meetings, with an attendance of 63,348, as contrasted with 60 societies holding 253 meetings with an attendance of 42,324 during 1912.

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MEETINGS IN ENGINEERING SOCIETIES BUILDING DURING 1913

| Meeting Room | Number of times occupied | | |
|---|---|---|---|
| | 1912 | 1913 | Change |
| Auditorium 3rd and 4th floors | 46 | 69 | 23 more |
| No. 1 Assembly Room 5th floor | 39 | 56 | 17 " |
| " 2 " " 5th " | 70 | 129 | 59 " |
| " 3 " " 5th " | 33 | 101 | 68 " |
| " 5 Lecture Room 6th " | 35 | 10* | 25 less |
| " 8 " " 6th " | 84 | 20* | 64 " |
| Small Committee Room 2nd " | 12 | 0* | 12 " |
| " " (Off Foyer) 1st " | 0 | 10 | 10 more |
| Assembly Room 1201 12th " | 0 | 18 | 18 " |
| Total | 319 | 413 | 94 " |

*No. 5 and No. 8 Lecture Rooms are now occupied by the American Museum of Safety, and the Small Committee Room on the second floor is used as a storage space by the National Electric Light Association. Room No. 1201 was occupied last year by the Efficiency Society.

## III. Library

During the year 1913 there were added to the Library of the three Founder Societies and United Engineering Societies, 3,566 volumes and pamphlets, of which 762 volumes and pamphlets were purchased at a cost of $2,078.04. The total number of books and pamphlets in the library at the end of the year is 54,245.

The attendance during the year was 11,091 as compared with 10,522 during 1912, an increase of 569 for the year 1913.

The department of research work has continued its activity during the past year. 168 searches have been made on a great variety of subjects in answer to requests received from correspondents in Patagonia, Korea, Japan, Australia, Mexico, South Africa, The Congo Free State, Alaska, Canada, and England, as well as from different parts of the United States. These searches have included the making of several hundred photographic reproductions. More than a thousand reference questions have been answered at the desk.

The Library receives more than 800 technical periodicals, which are available through indexes for research purposes.

Respectfully submitted,

Jos. Struthers,
*Treasurer.*

## UNITED ENGINEERING SOCIETY

### Balance Sheet, January 1, 1914

#### Assets

| | | |
|---|---|---|
| Real Estate—Land | | $ 540,000.00 |
| Real Estate—Building | | 1,050,000.00 |
| Real Estate—Equipment | | 27,357.16 |
| Furniture and Fixtures | | 5,795.46 |
| New York City Bonds 4½% 1917. | | 5,231.25 |
| New York City Bonds 4½% 1930-60 | | 5,062.50 |
| New York City Bonds 4½% 1962. | | 4,943.75 |
| Baltimore & Ohio Bonds | | 5,037.50 |
| Delaware & Hudson Company Bonds 4% 1943 | | 4,933.75 |
| Southern Railway Bonds 4% 1956 | | 4,755.00 |
| Library Books U. E. S. | | 329.07 |
| Library Adjustment Account | | 46.75 |
| Accounts Receivable | | 4564.18 |
| Unexpired insurance | | 960.83 |
| Cash: | | |
| Working Balance.. | $16,446.20 | |
| For Contingency and Depreciation | 10,000.00 | |
| Ways and Means Committee | 1,165.08 | |
| | | 27,611.28 |
| Petty Cash | | 500.00 |
| Interest Receivable | | 680.00 |
| | | $1,687,808.48 |

#### Liabilities

| | | |
|---|---|---|
| Balance of Land MortgageA.I.E.E.. | $54,000.00 | |
| Balance of Land MortgageA.I.M.E. | 34,000.00 | |
| | | 88,000.00 |
| A. I. E. E. Equity in Building | | 350,000 00 |
| A. S. M. E. Equity in Building | | 350,000.00 |
| A. I. M. E. Equity in Building | | 350,000.00 |
| A. I. E. E. Equity in Real Estate Equipment | | 3,346.61 |
| A. S. M. E. Equity in Real Estate Equipment | | 3,346.62 |

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| | |
|---|---|
| A. I. M. E. Equity in Real Estate Equipment | 3,346.62 |
| A. I. E. E. Payments to date in liquidation of mortgage on land | 126,000.00 |
| A. S. M. E. Payments to date in liquidation of mortgage on land | 180,000.00 |
| A. I. M. E. Payments to date in liquidation of mortgage on land | 146,000.00 |
| For Contingency and Depreciation | 40,000.00 |
| Ways and Means Committee | 1,165.08 |
| Library Adjustment Accounts | 75.45 |
| Accounts Payable | 1,070.14 |
| Surplus Account | 45,457.96 |
| | $1,687,808.48 |

UNITED ENGINEERING SOCIETY

STATEMENT OF RECEIPTS AND DISBURSEMENTS YEAR ENDING DECEMBER 31, 1913

CASH RECEIPTS

| | |
|---|---|
| Balance on hand January 1913 | $ 13,541.76 |
| Account of Interest on Mortgage | 3,240.00 |
| Assessment on Societies—Offices, Meetings, etc | 64,507.64 |
| Library Account | 8,175.27 |
| Interest on Bonds and Deposits | 1,783.76 |
| A.I.M.E. in reduction of mortgage | 40,000.00 |
| | $131,248.43 |

DISBURSEMENTS

| | |
|---|---|
| Account of Interest on Mortgage | $ 3,920.00 |
| Account of Real Estate Equipment | 732.44 |
| Operating Expense—Cash Expenditures | 38,035.40 |
| Furniture and Fixtures | 317.21 |
| Library Account | 8,175.27 |
| Bonds Purchased (Contingency and Depreciation Fund) | 4,943.75 |
| Accrued Interest on Bonds Purchased | 104.48 |
| Accounts Payable | 2,024.56 |
| A. I. M. E. Office Space Released | 4,084.00 |
| Insurance | 632.62 |
| Library Adjustment | 667.42 |
| Payment in reduction of mortgage | 40,000.00 |
| Balance on hand—January 1, 1914 | 27,611.28 |
| | $131,248.43 |

UNITED ENGINEERING SOCIETY

OPERATING INCOME AND EXPENSES, YEAR ENDING DECEMBER 31, 1913

INCOME

| | | |
|---|---|---|
| Assessment on Societies | $41,300.75 | |
| *Less*: Refund for office released | 3,435.00 | 37,865.75 |
| Assessment Miscellaneous (Offices and Meetings) | | 12,707.50 |
| Telephone Returns | | 4,836.68 |
| Miscellaneous Charges to Societies | | 3,622.17 |
| U. E. S. Library Returns | | 130.25 |
| Interest | | 1,679.28 |
| | | $60,841.63 |

EXPENSES

| | |
|---|---|
| Operating Expenses—Gross | $38,981.54 |
| For Contingency and Depreciation | 10,000.00 |
| Insurance | 1,034.48 |
| Depreciation on Furniture and Fixtures | 600.50 |
| Balance carried to Surplus Account | 10,225.11 |
| | $60,841.63 |

## Past Section Meetings

### BALTIMORE

The December meeting of the Baltimore Section was held in the physical laboratory of the Johns Hopkins University, Wednesday evening, December 17, 1913.

Two papers were presented: "The Growth of Electric Light and Power Service in Baltimore and Vicinity", by A. S. Loizeaux, and "How Susquehanna Power Keeps Pace with Baltimore's Industrial Progress", by R. B. Clapp.

This meeting was the first of several to be distributed through the year describing the steam and hydroelectric power systems supplying electrical energy to Baltimore and its vicinity. The papers of the evening were generally descriptive in their nature and outlined the various transformations of energy from the water plant or coal pile through the various steps to the consumer. Subsequent meetings will probably be held at power stations or substations and will aim to illustrate the matter brought out in the first papers. The papers were illustrated by lantern slides.

Chairman J. B. Whitehead presided. 51 members and guests were present.

The January meeting of the Baltimore Section was a joint meeting held in coöperation by the Department of Engineering of the Johns Hopkins University, the Baltimore Section, American Institute of Electrical Engineers, and the Baltimore Consolidated Section of the National Electric Light Association.

Two papers were presented: "The Hydraulic Plant of the Mississippi

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River Power Company at Keokuk, Iowa", by Mr. Walter Goodenough, read by Mr. A. S. Loizeaux, electrical engineer of the Gas and Electric Company; and "The Ozark Power and Water Company's Development on White River near Forsythe, Mo." by Mr. T. O. Kennedy, read by Mr. J. C. Lathrop, designing engineer of the Gas and Electric Company.

The papers were illustrated by a series of lantern slides. 106 were in attendance.

### Boston

A meeting of the Boston Section was held in the auditorium of the Engineers Club, December 18. The meeting was addressed by Mr. B. A. Behrend, consulting engineer, on the subject "A Great Engineering Disaster and the Lessons Learned Therefrom". The paper related specifically to the failure, while under test, of the first of a number of large waterwheel-driven generators made for the plant of the Niagara Falls Hydraulic Power and Manufacturing Company, in 1908. Mr. Behrend described in much detail the design of the generator, showing the reasons for the failure and the lessons obtained from the accident. At this meeting the causes of the failure were made public for the first time, the general design of this unit having originally been described in a paper by Mr. Behrend, July 1, 1908, read at the Atlantic City Convention.

The meeting was held jointly with the American Society of Mechanical Engineers and the Boston Society of Civil Engineers, with a total attendance of about 125. Mr. N. J. Neall, chairman of the Boston Section A.I.E.E., presided.

### Chicago

A joint meeting of the Chicago Section of the Institute and the Electrical Section of the Western Society of Engineers was held on Monday evening, January 26. The meeting was largely attended, about 300 members and guests being present. Mr. B. J. Arnold addressed the meeting on "City Transportation, Subways and Railroad Terminals", with lantern slide illustrations.

### Detroit-Ann Arbor

The Detroit-Ann Arbor Section held a meeting on January 16, at the Griswold House, Detroit.

After the conclusion of the business session, Professor A. R. Bailey of the University of Michigan gave an illustrated lecture on "Electrical Accessories for Gasoline Automobiles". After the paper a discussion was generally entered into, led by Messrs. J. O. Heinze, of the General Motors Company, Mr. W. H. Conant of the Gould Storage Battery Company, Mr. Knight of the Packard Motor Car Company, and other representatives of a number of the leading automobile manufacturers of Detroit.

Professor A. R. Sawyer, the chairman, presided, and the meeting was attended by 85 members and visitors.

### Fort Wayne

The Fort Wayne Section held a meeting on January 22, at the Fort Wayne Commercial Club, which was attended by 21 members and visitors. Chairman T. W. Behan presided. No regular program had been arranged, so the members took part in a general discussion of plans for the future meetings of the Section.

### Indianapolis-LaFayette

The January meeting of the Indianapolis-LaFayette Section was held at Indianapolis on January 16, and consisted of a trip to the power plants of the Indianapolis Light and Heat Company and the Merchants Heat and Light Company, and to the recently installed storage battery plant of the Indianapolis Light and Heat Company. These plants are thoroughly modern in their equipment, and opportunity was offered for inspection of both vertical and horizontal turbo-generators, as well as of engine type generators, embodying the developments made in the last few years by the large electrical companies

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of this country. The storage battery plant is capable of carrying its company's total load of the downtown section of the city for twenty minutes, in case of accident to the power plant.

Transportation was kindly furnished for those who attended by the two companies whose plants were visited, and a lunch was served by the Merchants Heat and Light Company at their plant. Members and visitors to the number of 120 participated in the inspection trip.

### Los Angeles

The monthly meeting of the Los Angeles Section was held at Music Hall, Blanchard Building, on January 20, with 84 members and visitors present. The paper of the evening was presented by Mr. P. S. Taylor, entitled "The Electrical Precipitation of Dust from Rotary Cement Kilns".

The paper was supplemented by a discussion in detail by Mr. Walter A. Schmidt, who is associated with Mr. Taylor in the application of the system and conducted the experimental work. The paper as presented proved exceptionally interesting and was discussed in an informal manner by Messrs. Nye, Lighthipe, Panter and Warren.

Mr. Wesley H. Beach, attorney for the ranchers surrounding the Riverside Portland Cement Company, was in attendance and spoke briefly on the subject from their standpoint, expressing satisfaction with the results thus far obtained.

Dr. H. B. Morse, chemistry lecturer at Berkeley, gave an interesting talk on the subject of electrical precipitation of dust.

### Lynn

The third annual banquet of the Lynn Section was held on January 24, at the New American House, Boston. There were 240 members and guests present.

The decorations were chiefly illuminating effects, letters spelling out "American Institute of Electrical Engineers" and "Lynn Section", and a large transparency showing the new emblem of the Section in green and white with gold letters.

At the head table were Messrs. E. R. Berry, chairman, and J. A. McManus, Jr., secretary, of the Section; President C. O. Mailloux; W. A. Hall, toastmaster of the banquet; Thomas D. Lockwood, general patent attorney of the American Telephone and Telegraph Company; Professor Harry E. Clifford, Harvard University; W. C. Fish, manager of the Lynn Works, General Electric Company; and Mr. D. B. Rushmore, power and mining engineer, General Electric Company, Schenectady, N. Y.

Mr. Hall, in his introductory remarks, reviewed the past history of the Lynn Section, and pointed out the various factors which have been responsible for its remarkable success. Mr. Hall also read a letter from Professor Elihu Thomson, expressing his regret at not being able to be present on account of an engagement in Philadelphia.

President Mailloux, during the course of his remarks, likened the Lynn Section to Caesar's 10th legion and to Napoleon's old guard, and stated that it was up to the members to keep up their present enthusiasm and see that the Section held its place in the forefront. He expressed the hope that the Section would be well represented at the International Electrical Congress which is to be held in San Francisco next year.

Mr. Thomas D. Lockwood, the principal speaker, is a well-known telephone pioneer, and has been a member of the A. I. E. E. since its earliest days. He interspersed anecdotes of electrical discovery and invention with humorous tales, which were greeted with laughter and applause. He pictured the early man as without resources of strength and speed, which characterize the brute creation, but endowed with the divine spark of intellect and the power of invention, and he called to mind the early work of such electrical pioneers as Stephen Gray, Galvani, Volta and Ampere.

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He spoke of the telephone as a factor in modern business, and explained how the multiple switchboard had become a great time-saving factor in the use of the telephone, estimating that this device saved 357,847 days to the people of this country alone in one year. From his long connection with the patent end of the business, Mr. Lockwood told many interesting and amusing stories of inventions which became famous.

Remarks were also made by Mr. W. C. Fish, Professor Harry E. Clifford and Mr. D. B. Rushmore.

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The regular meeting of the Lynn Section, held on Wednesday evening, February 4, in Third D of the plant of the General Electric Company, brought out one of the largest audiences of the year, 378 members and visitors, to hear Mr. W. B. Potter, engineer of the railway department of the General Electric Company, who spoke on the subject of "Electrification of Railroads".

Mr. Potter was introduced by Prof. Elihu Thomson, who said that Lynn was a pioneer in the manufacture of railway motors, and that as early as 1887 the application of electric power to the electric car had been solved. Professor Thomson also stated that electrification of street railways on a large scale was first put into successful operation in Boston, when Mr. Henry M. Whitney, who was then president of the West End Railway, placed the order to equip that public service line with electric passenger cars.

Mr. Potter took up first the subject of the steam locomotive and described the different types which were used for various kinds of service, and outlined the mechanical features of engines used by the railroads of the country. He pointed out the great waste of power caused by various influences which rendered impossible the full utilization of the energy generated by the coal consumed.

The point has now been reached when the power of the larger locomotives is so great that a fireman cannot pass a sufficient amount of coal to maintain the full output from the engine. On this account such locomotives using coal are being generally equipped with mechanical stokers, or oil is the preferred fuel where its price is not prohibitive. While the steam road for heavy traffic over long distances is still the accepted standard for transportation, the electric road for urban, interurban and local service is fast displacing steam.

Mr. Potter described the early types of street cars and told of attempts to operate these by means of the gasoline engine, compressed air and storage batteries, but none of these proved successful, and not until the electric railway motor was brought out, was the horse displaced on our city streets. To-day the electric system of transportation has gone far beyond the conventional trolley, and railway trains are being operated over long distances and at a speed equal to that of steam trains.

Mr. Potter's lecture was illustrated with many lantern slides showing railway construction and equipment in nearly every country of the world and illustrating clearly the different types of electric locomotives and cars.

### Mexico

Instead of holding a regular meeting on the evening of January 20, the members of the Mexico Section and their friends repaired to the Cine Palacio in Mexico City, to see a series of moving pictures illustrating the manufacture and use of electrical devices, which was shown by Mr. H. W. Gottfried.

The first reel, called "The Electrical Education of Mr. and Mrs. Thrifty", presented all the latest electrical devices for lighting, heating, and cooking. The next was entitled "What is Behind the Button", and showed the immense factories devoted to the manufacture of electrical apparatus of every kind. The third reel showed the workshops, with mechanics engaged in putting these

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devices together, and the last one pictured the manufacture of electric meters, fan motors and other equipment.

There was an attendance of 30 Institute members and 360 visitors.

### Milwaukee

The joint meeting of the Milwaukee Engineers' Society and the Milwaukee Section of the A. I. E. E. was held Wednesday evening, January 14, in the Plankington House. A paper was read by Professor Daniel W. Mead, consulting engineer and professor at the University of Wisconsin. The subject of this paper was " The Present Status of Water Powers of Wisconsin ". The lecture was illustrated by lantern slides showing a number of waterpower developments in Wisconsin. Details were given as to the amount of power which was now being developed in the state and also the amount which could be developed, together with estimates as to the cost of this development.

Mr. Emil Vilter presided, and the total attendance was 140.

### Minnesota

The regular monthly meeting of the Minnesota Section was held on January 19, in the Ryan Hotel, St. Paul. Professor W. T. Ryan, chairman, presided, and the total attendance was 65. The meeting was preceded by a dinner which was attended by some forty members and visitors.

Mr. E. B. Street, engineer of the Consumers' Power Company, St. Paul, presented a paper on " The Operation of the Consumers' Power Company's Steam Heating and Electrical Generating Station in St. Paul ". This paper gave rise to considerable discussion of the question of steam heat distribution.

The next paper, on " The Alternating-Current Synchronous Motor ", was presented by Mr. Theodor Schou, chief engineer of the Electric Machinery Company, formerly with the Westinghouse Company. His paper was profusely illustrated with specially prepared lantern slides, giving in concise form many valuable data on this subject.

### Philadelphia

The Philadelphia Sections of the A. I. E. E. and the American Society of Mechanical Engineers held a joint meeting on February 9, at the Engineers' Club, at which the attendance was 172. Messrs. A. R. Cheyney and D. R. Yarnall presided.

The subject of the evening was "Business Training for the Engineer ". The first paper was given by Dr. Alexander C. Humphreys, who was followed by Mr. T. I. Jones. The papers were discussed by Professor H. H. Norris, Dr. Walter Clark, Professor George A. Hoadley, Messrs. Henry Hess, Charles H. Bigelow, H. V. Schreiber, Allen, Tabor, Wein, Miller and W. C. L. Eglin. The discussion was closed by Dr. Humphreys and Mr. Jones.

There were 82 men present at the dinner preceding the meeting. The meeting was followed by the usual smoker, which did not break up until midnight.

### Pittsburgh

The Pittsburgh Section held its regular meeting on January 13, in the Oliver Building. The meeting was attended by 75 members and visitors. Chairman A. M. Dudley presided.

The general subject of the meeting was " The Application of Electricity to Automobiles. " Two papers were presented, as follows: " Construction and Operation of Electric Trucks, " by Mr. T. H. Schoepf, and " Electrical Equipment for Automobile Gas Engines" by Mr. C. E. Wilson.

Both papers were illustrated with lantern slides, and called forth an interesting discussion, in which Messrs. Joseph Breslove, E. L. Farrar, K. C. Randall, George Criss, G. M. Eaton, A. P. Sunnergren, G. M. Kinney, E. A. Regestein, J. M. Hipple, A. H. McIntire, and A. B. Reynders took part.

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### PITTSFIELD

The sixth meeting of the 1913-1914 season of the Pittsfield Section was held in the Berkshire Athenaeum on January 22. The speaker of the evening was Mr. W. S. Andrews of the consulting engineering department of the General Electric Company, who took as his subject, "Pioneer Electric Lighting."

Mr. Andrews showed a number of interesting lantern slides, illustrating the early work of Mr. Edison in connection with incandescent lighting.

Mr. W. W. Lewis presided at this meeting, which was attended by 50 members and visitors.

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The seventh meeting of the Section was held January 29, the speaker being Mr. H. W. Tobey, of the transformer engineering department of the General Electric Company.

Mr. Tobey's subject was, "Large Hydraulic Power Plants." Special attention was paid to the Mississippi River and Eastern Michigan systems, which were recently visited by the speaker.

The talk was illustrated by means of lantern slides, showing the construction used on these systems, as well as on other systems in the United States and Europe.

The attendance at this meeting was 65.

### PORTLAND

On January 6, the Portland Section of the A. I. E. E. held a joint meeting with the local section of the N. E. L. A. in the assembly rooms in the Hawthorne Building of the Portland Railway, Light and Power Company.

The paper of the evening was presented by Mr. B. S. Durkee, of the Postal Telegraph Company, on "Duplex and Quadruplex Telegraphy." Following this paper Mr. A. S. Moody delivered a lecture on "The Hydro-electric Developments on the Pacific Coast," with lantern slides.

Mr. A. E. West presided, and the attendance was 30.

The A. I. E. E. and N. E. L. A. Sections held a joint meeting on Tuesday, February 3, in the assembly rooms of the Hawthorne Building. About forty members of the two organizations were present.

A paper entitled "New and Proposed Regulations Affecting Water Power Development" was presented by Mr. L. F. Harza. This paper will be published in the *Journal of Electricity, Power and Gas*, San Francisco, California.

Mr. C. N. Huggins, secretary and treasurer of the Portland Railway, Light and Power Company, read and discussed Mr. Ralph D. Mershon's paper on "Some Things Engineers Should Know Concerning the Rudiments of Corporate Finance."

The attention of the members was called to the Pacific Coast meeting of the A. I. E. E. and the meeting of the Northwest Electric Light Association to be held at Spokane September 9, 10 and 11, 1914.

### SAN FRANCISCO

The San Francisco Section held a meeting on January 23, at Native Sons Hall. Chairman A. H. Griswold presided.

Mr. Guy L. Bayley, electrical and mechanical engineer for the Panama-Pacific International Exposition, delivered an address and gave a comprehensive exhibition of the lighting and electrical features of the exposition to be held in San Francisco in 1915. Mr. Bayley's talk was profusely illustrated with lantern slides.

The meeting was attended by some 250 visitors and members, being one of the largest meetings in the history of the San Francisco Section, thus showing the great interest being taken in the Exposition.

Prior to the meeting about sixty members and guests dined at the Hof-Brau Cafe.

### SCHENECTADY

The Schenectady Section gave a midwinter smoker on January 24, in

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the Edison Club Hall, under the direction of the "Get-Together Committee", Messrs. A. W. Clark, chairman, Chester Lichtenberg, R. E. Rugen and Robert Treat. The members of the Edison Club, an organization of General Electric Company engineers, were invited to be the guests of the Schenectady Section. An interesting program was presented and light refreshments were served. Four hundred members and guests were present.

### SEATTLE

The Seattle Section held a meeting on January 21 at the Chamber of Commerce. This being the first meeting of the year 1914, the officers elected at the previous meeting were installed, Mr. S. C. Lindsay, of the Puget Sound Traction, Light and Power Company, as chairman, and Mr. E. A. Loew, of the University of Washington, as secretary.

Chairman Lindsay announced the membership of committees, as follows: executive committee, Messrs. C. F. Terrell, chairman, Robert Howes, Glen Dunbar; program committee, Messrs. Percy Ridgeway, chairman, L. F. Curtiss, T. S. Clark; membership committee, Messrs. W. R. Hendry, chairman, R.L. Rockwell, A.E. Ransom.

The program of the evening consisted of a paper by Mr. F. A. Phipps entitled "Modern Steel Electric Furnaces." The discussion which followed was participated in by Messrs. Harisberger, Magnusson, Lindsay, Price, Miller and Terrill. There were presented some interesting data on the cost of the production of steel castings from steel scrap by means of an electric furnace installed at the Washington Iron Works' Seattle plant.

The total attendance at the meeting was 33.

### SPOKANE

The third meeting of the current year of the Spokane Section was held on December 19 in the Silver Grill. The business meeting was preceded by an informal dinner which began at 6.30 p. m. The trip to be conducted on January 17 to the University of Idaho at Moscow, including a joint meeting with the local sections of the A. S. C. E. and the A. I. M. E., was discussed in detail, addresses being made by representatives from the other societies and by Professor Carpenter of the Washington State College at Pullman, who promised to head a delegation from that school.

After the discussion of the Moscow trip, the committee on advice to the library was announced to consist of Mr. L. N. Rice, Mr. V. H. Greisser and Mr. B. F. Olds. It is hoped that this committee will prove of valuable assistance to the City Librarian in the selection of electrical books which may be purchased in the future.

The event of the evening was a paper entitled "Efficiency in the Meter Department," by Mr. J. G. Finley. Mr. Finley described a number of labor-saving devices which have made it possible to handle watt-hour meters in the testing room with the maximum speed. After discussion, which was participated in by practically everyone present, the meeting adjourned at 10.30 p.m. Chairman J. B. Fisken presided. The attendance was 48.

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The regular January meeting of the Spokane Section was held on Friday, January 16, in the Silver Grill. The meeting was held subsequent to an informal dinner and was presided over by Chairman J. B. Fisken. There was an attendance of 28. The paper of the evening, "Inductive Interference in Telephone Practise," by H. A. Shearer, was read and discussed at length.

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On the following day a trip to the University of Idaho at Moscow, Idaho, was conducted jointly by the Columbia Chapter of the American Institute of Mining Engineers, the Spokane Association of the American Society of Civil Engineers and the Spokane Section of the A. I. E. E. The electrical paper was by Mr. J. B. Fisken and covered the

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construction of the Little Falls tie line of the Washington Water Power Company. The trip was conducted on a special train styled the "Engineers' Special," and was pronounced an unqualified success by all who attended. The total attendance on the trip was 65, not counting over a hundred students who came over from the Washington State College at Pullman.

### Toledo

The Toledo Section held a meeting on February 6 at the Toledo Commerce Club.

Professor E. B. Thurston of the Ohio Northern University addressed the meeting on alternating-current machinery, beginning with polyphase induction motors, synchronous motors and repulsion motors. The speaker explained the theories of these different types, illustrating with blackboard sketches. A general discussion followed.

Chairman George E. Kirk presided at the meeting. The attendance was 25.

### Toronto

The second regular meeting of the Toronto Section for the season was held at the Engineers Club, Toronto, on the evening of January 30, 1914. Chairman D. H. McDougall presided, and the meeting was attended by 97 members and visitors.

Mr. N. W. Storer, of the Westinghouse Electric and Manufacturing Company, delivered an address on "The Electrification of Steam Railways." This subject proved very interesting and Mr. Storer's address was followed by a lively discussion in which Messrs. Gaby, Case, Hewson, Hart and McDougall took part.

### Urbana

The Urbana Section held a meeting on January 16 in the electrical engineering laboratory of the University of Illinois. Mr. J. H. Belt presented in abstract the three recent Institute papers on electrical equipment of gasoline automobiles, by Messrs. Alfred E. Waller, Alexander Churchward and Frank Conrad.

Chairman Morgan Brooks presided, and the total attendance was 56.

## Personal

Mr. Walter C. Wagner has resigned his position as chief engineer in the government service to take up private practise as consulting engineer at 1128 Henry Building, Seattle, Wash. He is now engaged as designing, purchasing and constructing engineer for the Brookings Timber and Lumber Company, which is erecting a power plant and large electrically driven sawmill at Brookings, Oregon.

Professor Vladimir Karapetoff of the electrical department of Cornell University recently delivered a course of four two-hour lectures in Washington, D. C., before the engineer officers of the United States Army, Washington Barracks. The subjects treated were "Alternating Currents", "Theory of Electrical Machinery", "Design of Electrical Machinery", and "The Fundamentals of the Magnetic Circuit."

Mr. William C. Parrish, formerly manager of the Central Oregon Power and Irrigation Company, Walla Walla, Wash., is now located in Boise, Idaho, working on a special assignment of writings of a technical nature covering the development of the industries and resources of that territory. The holdings of the Central Oregon Power and Irrigation Company have been taken over by interests identified with a Carey Act withdrawal covering 5000 acres in and around Malheur Lake, which is to be reclaimed by pumping. Mr. Parrish has a financial and engineering interest in this enterprise.

Mr. E. F. Sherwood was appointed chief engineer of the Eastern group of Bell telephone companies on January 1. Mr. Sherwood became an operator in the office of the Law Telegraph and

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Telephone Company in New York City in 1879, and rose to the managership of that system. When that business was taken over in 1884 by the Metropolitan Telephone and Telegraph Company Mr. Sherwood was placed in charge of the traffic department of the telephone company, which position he has held for the past thirty years. Mr. Sherwood's career is therefore inseparably linked with the development of the telephone business in New York.

## Obituary

JULIUS C. CALISCH, Mem. A. I. E. E., traction engineer, of the New York office of the General Electric Company, died on November 28, 1913, after a brief illness. He was born in New York City, October 18, 1867. After being graduated from Stevens Institute of Technology in 1887, Mr. Calisch became engaged in the development of storage battery systems with the Electrical Accumulator Company. He then entered the service of the Edison United Manufacturing Company, which later became the General Electric Company, and was in charge successively of their Pittsburgh and Buffalo districts. On December 19, 1902, Mr. Calisch was elected an Associate of the A. I. E. E. In 1908 he left the General Electric Company to become the vice-president and general manager of the Buffalo and Lake Erie Traction Company. Under his supervision an electric road was built between Buffalo and Erie, Pa., with feeder lines reaching intermediate districts, which is considered one of the best pieces of inter-city railroading in the country. Upon the completion of this work Mr. Calisch returned to the General Electric Company, coming to the New York Office as an advisory expert in traction matters, where he remained until his death. It was on May 20, 1913, that Mr. Calisch was transferred to the grade of Member of the Institute.

GEORGE RUTHERFORD KEMPTON, Assoc. A. I. E. E., local superintendent for the Southern Sierras Power Company at San Jacinto, California, died on January 3, 1914, at Riverside, Cal. His death was the result of an accident on the day before, at Hemet, near San Jacinto, when an electric light pole which was being reset got away from the gang and struck Mr. Kempton at the base of the skull. He did not recover consciousness, and died the next day. George Rutherford Kempton was born at Amenia, N. Y., November 22, 1876, and received his technical education at the Drexel Institute, Philadelphia, and Tufts College, Massachusetts, from which he was graduated in 1900 with the degree of B. S. in electrical engineering. After some experience on hydroelectric development work in Maine, and in the testing department of the General Electric Company at Schenectady, Mr. Kempton was engaged as electrical engineer in the office of the Supervising Architect, U. S. Treasury Department, Washington, D. C., in charge of electrical work. In 1905-1906 he was electrical engineer for the U. S. Reclamation Service, at Denver, Colorado. During the next six years he was successively superintendent of the Laramie, Wyoming, Light and Power Company, manager of the Kane, Pennsylvania, Electric Light and Power Company, and manager of the Olean, New York, Electric Light and Power Company. He was elected an Associate of the Institute on June 25, 1913. It was on November 12, 1913, that he left his father's home in Buffalo to take up his new work in California.

WALTER AMBROSE PEARSON, Mem. A. I. E. E., died in New York City on January 25, 1914. He was born in Putnam, Conn., July, 1869. He was educated at Tufts College, Mass., and was graduated with the degree of B. A. in the class of 1890. Immediately upon his graduation he entered the employ of the West End

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Street Railway Company, of Boston, which was then going through the early stages of electric railway development. Mr. Pearson was employed first as a station operator. In 1893 he went to Brooklyn, N. Y., as electrical engineer in charge of the electric installation of the then Brooklyn Heights Railroad Company. In 1896 he became electrical engineer for the Metropolitan Street Railway Company of New York City, and was particularly active in the development of the Lenox Avenue underground electric system, which was the first underground electric system to be developed in this country. On April 23, 1903, he was elected an Associate of the Institute, and was transferred to the grade of Member on November 20 of the same year. Mr. Pearson remained with the Metropolitan Street Railway Company until 1906. He then went to Niagara Falls for the Electric Development Company of Ontario, in charge of the electrical installation and construction of that company's power house at Niagara Falls. In 1910 he went to Rio de Janeiro, Brazil, and there remained for two years as assistant general manager of the Rio de Janeiro Tramway, Light and Power Company. He returned to the United States in 1912, owing to poor health in the tropics, and became associated with the banking house of Bertron Griscom and Company, with whom he was connected at the time of his death, as consulting electrical engineer.

Mr. Pearson was also a member of the American Society of Mechanical Engineers, the New York Railroad Club and the Engineers Club of New York.

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LAWRENCE A. COBB, of the General Plant Department of the Mountain States Telephone and Telegraph Company, at Denver, Colorado, died suddenly during the night of February 14, 1914. He was born in St. Louis, Mo., November 24, 1883. His education was received at the St. Louis Central High School, and in a three years' course at Washington University, St. Louis, ending in 1909. During a part of this time Mr. Cobb was engaged as meter tester and assistant wireman for the Union Electric Company, St. Louis. From 1909 to February, 1911, he was assistant to the engineer of the St. Louis Refrigerating and Cold Storage Company, and then took up his telephone work, as exchange engineer and assistant construction engineer with the Bell companies, first in St. Louis and then in Denver. Mr. Cobb had made application for election as an Associate of the Institute, but the news of his death was received before his election could be completed.

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## Abstracts of Proceedings of Foreign Engineering Societies

### SOCIETE INTERNATIONALE DES ELECTRICIENS.

### MEETING OF JANUARY 7, 1914

" Contribution to the Study of Variations of Ferromagnetism as a Function of Temperature," by M. P. Dejean.

This work comprises a systematic study of a series of steels with increasing carbon contents, from 0.06 to 1.6 per cent. Owing to the use of a special device constructed for this particular purpose, the variations of induction in a constant magnetic field, during the heating and cooling of the steel samples, could be automatically recorded.

This investigation has shown that:

1. In the case of cylindrical samples, the results were entirely dependent on whether the length of the sample was equal to a small number of its diameters, or was, on the contrary, many times the diameter. In the first case the demagnetizing influence of the poles materially alters the course of the phenomenon.

2. The disappearance of the magnetism occurs in two discontinuous periods. The first corresponds to the critical point $A$ and is reversible (occurs at the same temperature, both on heating and on cooling); the second is the critical point $A_2$ and is irreversible.

3. At about 200 deg. cent. a fall of

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permeability is encountered, corresponding to the loss of magnetism of iron carbide $Fe_3C$.

4. A soft, very much oxidized, steel has proved to be abnormal up to a temperature of 250 deg. cent. Above this temperature it becomes normal, both while heated and while cooled.

5. A curve of heating of a previously tempered steel exhibits a local maximum of permeability at 300 deg. cent.

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"Concerning the Criterion of Good Commutation of M. Mauduit, and Commutation with the Load Variable," by M. Guéry.

As a conclusion to the papers which he presented before the Société Internationale des Electriciens in December, 1912, and January, 1913, M. Mauduit has given a definition of a criterion of good commutation on a neutral theoretical line, so as to present in a simple manner the conclusion of the general considerations which he presented in the said papers. It is of interest to investigate the practical value of such a criterion. This criterion consists in showing that the average electromotive force induced in a section under commutation is less than a certain value $E_\gamma$ defined by the conditions of contact of the commutator brushes. This average electromotive force may be considered as a sum of two other e.m.fs., the first, $E_\gamma$, due to the rotation of the section in an armature field assumed to be fixed, and another, $E_s$, due to the self-inductance of a leakage circuit belonging to the section under consideration.

This criterion may be therefore expressed in a general manner as follows:

$$E_\gamma + E_s \leq E_r$$

I. *Machines with projecting poles.* It is easy to show that in this case the lines of force of the leakage circuit do not exist: $E_s = 0$. The permissibility of using this criterion would therefore be established if one could prove that the armature field can be considered as fixed. With respect to that, one can show that:

1. Contrary to what appears to be generally admitted, linear commutation makes the armature field fixed in only exceptional cases.

2. On the contrary, owing to numerous causes of damping which exist in the majority of machines, the pulsating flux due to the balancing of the armature field is, very generally, to a large extent damped out.

The criterion has then a precise significance, $E_\gamma$ being the electromotive force which opposes commutation in a short-circuited section. For the exceptional case when the pulsatory flux is not damped out, one can show that the criterion, without having a precise significance, gives indications tending to show the actions opposing good commutation. The saturation of the magnetic circuit appears to have no effect, particularly when the pulsating flux is damped out.

II. *Formula for the number of segments.* The formula of criterion can be transformed so as to bring out constructive data. We denote by:

$q$ the number of commutator segments,

$m$ the number of pairs of circuits in parallel between the brushes,

$B$ average induction in the air-gap,

$k$ number of amperes per cm. of the developed armature,

$E$ voltage at the terminals.

Then $$q = K\frac{mkE}{B}$$

where $K$ depends on the constructional details of the machine which vary but little from one type to another, and also on the voltage $E_\gamma$: it must have a value in the neighborhood of 12.

III and IV. *Machines with commutating poles and compensated windings.* For this case one shows easily that, after having eliminated $E_\gamma$, one has yet to eliminate $E_s$, the lines of force of the leakage field exercising all their influence after the general armature field has been compensated.

V. *Synchronous converters.* In this case $E_\gamma$ does not exist at all, and there

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is only $E_s$. If there are no commutating poles, $K$ has a value between 6 and 10.

VI. *Variable load.* With a sudden variation of load, there may be a skin effect in the commutator segments. By a series of approximative calculations it is shown that the local increase in density of current may be up to 2.4 times that of the normal. It would be interesting to make an oscillographic study of variable load conditions in continuous-current dynamos, so as to obtain an idea of the speed of variation in intensity and the real value of the points.

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Discussion on "Commutation," by M. Gratzmuller.

The author refers to the general theory of commutation presented to the Société Internationale des Electriciens in January, 1913. The application of this theory to certain special cases is considered next. The commutation at zero electromotive force may occur in the full field.

With multiple windings, the equipotential connections place the alternators in parallel and insure an equal distribution of flux; by this means windings in series and series-parallel may be obtained. A good commutation cannot be derived only from the distribution of currents on the surface of a brush. The author establishes, among other things, the theory of windings and shows its analogy to that of regular polygons. The author derives a theory of the arc between brushes. If the difference of potential between the segment which has just been left by the brush, and the brush itself, is too high, an arc is started. If this difference of potential is not due to the self-induction of the section exclusively, it stays and may even rapidly increase in high-voltage dynamos. The successive sections all create arcs, which causes a short circuit between the brushes and the starting of an arc between them. Since, according to the law of Maxwell, the flow of current tends to embrace the maximum flux, it goes out of itself, and the arc disappears when the cause of disturbance disappears. The author then describes the commutation in electrolysis machines, continuous-current dynamos driven by steam turbines, and dynamos working at very high voltages. He points out that the device which he recommends brings into play at the commutator only the unit of electromotive force developed in a segment or a fraction of a segment. He also indicates a new device for driving continuous-current dynamos by means of steam turbines at reduced speeds, by using simultaneously the movements of the distributor and of the blades.

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## Library Accessions

The following accessions have been made to the Library of the Institute, since the last acknowledgment.

L'Académie des Sciences. Tables Générale des Comptes Rendus. Vols. 92-121, 1881-1895. Paris, 1900. (Purchase.)

American Electricians' Handbook. Compiled by T. Croft. New York, 1913. (Purchase.)

American Institute of Electrical Engineers. Year-Book 1914. New York, 1914. (Gift)

Annuaire de L'Electricité edité par La Lumière Electrique 1914. Paris, 1914. (Gift of Lumière Electrique.)

Annuaire du Bureau des Longitudes. 1914. Paris, Gauthier-Villars, 1914. (Gift of publisher.)

Betriebsergebnisse elektrischer Zentralen. By Adolf Ludin. (Sonderabdrick aus "Elektrotechnik und Maschinenbau Heft 15, 1912) n.p. n.d. (Gift of author.)

Cours de Physique Générale. Tome I. By H. Ollivier. Paris, A. Hermann et Fils, 1913. (Gift of publishers.) Price 18 fr.

The author is connected with the University of Lille, and the work is to be used as a general text book. The first volume is devoted almost entirely to electricity and magnetism. W. P. C.

Electric Light and Motor Wiring. By Geo. J. Kirchgasser, Milwaukee, Electroforce Pub. Co., 1913. (Gift of author.)

The author is an associate member of the Institute. The book is vest-pocket size, and is a practical handbook, giving directions for wiring on the basis of the National Electrical Code requirements. W. P. C.

Graphite. Vols. 13-15, Jersey City, 1911-13. (Gift of Joseph Dixon Crucible Co.)

Handbook of Electrical Methods. Compiled from the Electrical World. New York, 1913. (Purchase.)

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Jahrbuch der Elektrotechnik. Erster Jahrgan, 1912. By Karl Strecker. München, 1913. (Purchase.)

Light Railway & Tramway Journal Diary, 1914. London, 1914. (Exchange.)

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New York State. Public Service Commission for the First District. Report Vol. 1, 1912. Albany, 1913. (Exchange.)

Philadelphia. Electrical Bureau. Annual Report of the Chief for year ending Dec. 31, 1912. Philadelphia, 1913. (Gift of C. W. Pike.)

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Die Wirschaftlichkeit des geplanten Murgwerkes. By Adolf Ludin. (Sonderabdruck aus Zeitschrift fur die gesamte Wasserwirtschaft, 1912, pt. 13-15.) N.p.n.d. (Gift of author.)

Workshop Receipts, for the use of manufacturers, mechanics and scientific amateurs. By Ernest Spon. London-New York, 1873. (Purchase.)

### Gift of American Electric Railway Association

California. Railroad Commission. Report. Jan. 1909-June 30, 1910; Jan. 1911-June 30, 1912. 2 Vols. Sacramento, 1910-1912.

Florida. Railroad Commission. Annual Report 13th, 1910. Tallahassee, 1910.

Illinois. Railroad and Warehouse Commission. Annual Report 42d 1912, Vols. 1-2. Springfield, 1913.

Kansas. Railroad Commissioners. Report of the Board. 21st. Topeka, 1910.

Nebraska. State Railway Commission. Annual Report 5th, 1912.

New Jersey. Board of Public Utility Commissioners. Annual Report 3d, 1912. Union Hill, 1913.

New York Street Railway Association Annual Reports 1898-1902.

### Gift of A. E. Kennelly

A convenient form of continuous current artificial line. (reprinted from Electrical World, June 14, 1913.)

Daylight Effect in Radio Telegraphy. (reprinted from Proceedings of the Institute of Radio Engineers, July 1913.)

Disturbances of Potential and Current Produced in an Active Conducting Network by the Application of a Leak Load. (reprinted from Electrical World, Dec. 28, 1912.)

Test of an Artificial Aerial Telephone Line at a Prequency of 750 cycles per second. By A. E. Kennelly and F. W. Lieberknecht. (A. I. E. E. meeting June 24, 1913.)

### Trade Catalogues

Allgemeine Elektricitäts Gesellschaft. Flammeco-Lampen fur Fabrikbeleuchtung Lehrmittelumformer für experimentelle Zwecke.

Federal Storage Battery Car Co. Silver Lake, New Jersey.—Bull. No. 31—Beach cars, propelled by Edison batteries.

——Bull. No. 32—Beach cars, type 301.

Leeds & Northrup Co. Philadelphia, Pa. Catalogue No. 44, Reistance boxes and Wheatstone bridges.

Ohio Brass Co. Mansfield, O.—Bull. Nov.-Dec. 1913.

### United Engineering Society

American Year Book 1913. New York, 1914. (Purchase.)

Engineering Index, 1913. New York, 1914. (Purchase.)

An Expensive Experiment. The Hydro-electric Power Commission of Ontario. By R. P. Bolton. New York, 1913. (Gift of author.)

International Acetylene Association. Proceedings of 16th Annual Meeting, 1913. (Gift of Association.)

Metal Statistics, 1914. 7th ed. New York, American Metal Market Co., 1914. (Gift of publisher.)

Michigan Gas Association. Proceedings of the 22d Annual Meeting, 1913. N.p. 1913. (Gift of Association.)

New York Times Index. Oct.-Dec. 1913. New York, 1913. (Purchase.)

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Universal Elements and their Prime Combinations. By Julius L. Hornig. Jersey City, 1913. (Gift of author.)

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Term expires July 31, 1916.

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Term expires July 31, 1914.

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Term expires July 31, 1914.

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(Continued.)

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Revised to March 1, 1914.

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| **Baltimore**.....Dec. 16, '04 | J. B. Whitehead. | L. M. Potts, Industrial Building, Baltimore, Md. |
| **Boston**.....Feb. 13, '03 | N. J. Neall | Harold G. Payne, (Acting Secretary) 12 Pearl St., Boston, Mass. |
| **Chicago**..... 1893 | D. W. Roper. | E. W. Allen, 1028 Monadnock Building, Chicago, Ill. |
| **Cleveland**.....Sept. 27, '07 | J. C. Lincoln. | R. E. Scovel, 1663 East 86th Street, Cleveland, Ohio. |
| **Detroit-Ann Arbor**.Jan. 13, '11 | A. R. Sawyer. | Ray K. Holland, Cornwell Building, Ann Arbor, Mich. |
| **Fort Wayne**.....Aug. 14, '08 | T. W. Behan. | P. H. Haselton, Fort Wayne Electric Works Ft. Wayne, Ind. |
| **Indianapolis-Lafayette**.Jan. 12, '12 | O. S. More. | G. B. Schley, 805 Pythian Building, Indianapolis, Ind. |
| **Ithaca**.....Oct. 15, '02 | E. L. Nichols. | George S. Macomber, Cornell University, Ithaca, N. Y. |
| **Los Angeles**.....May 19, '08 | E. R. Northmore. | C. G. Pyle, 914 Hibernian Bldg., Los Angeles, Cal. |
| **Lynn**.....Aug. 22, '11 | E. R. Berry. | J. A. McManus, Jr., General Electric Co., Lynn, Mass. |
| **Madison**.....Jan. 8, '09 | Edward Bennett. | F. A. Kartak, Univ. of Wisconsin, Madison, Wis. |
| **Mexico**.....Dec. 13, '07 | Norman Rowe. | James Carson, Mexican Light and Power Company, Mexico City, Mexico. |
| **Milwaukee**.....Feb. 11, '10 | L. E. Bogen. | L. P. Coulter, 2500 Chestnut Street, Milwaukee, Wis. |
| **Minnesota**.....Apr. 7, '02 | W. T. Ryan. | Fred G. Dustin, 9 South Fifth St., Minneapolis, Minn. |
| **Panama**.....Oct. 10, '13 | Edward Schildhauer. | W. R. McCann, Isthmian Canal Commission, Culebra, Canal Zone |
| **Philadelphia**.....Feb. 18, '03 | A. R. Cheyney. | H. F. Sanville, 1326 Chestnut St., Philadelphia, Pa. |
| **Pittsburgh**.....Oct. 13, '02 | A. M. Dudley. | E. R. Spencer, 814 Frick Building, Pittsburgh, Pa. |
| **Pittsfield**.....Mar. 25, '04 | J. J. Frank. | G. W. Wade, General Electric Company, Pittsfield, Mass. |
| **Portland, Ore**.....May 18, '09 | G. P. Nock. | R. F. Monges, G. E. Co., Electric Building, Portland, Ore. |
| **St. Louis**.....Jan. 14, '03 | F. J. Bullivant. | A. McR. Harrelson, Emerson Electric Mfg. Co., St. Louis, Mo. |
| **San Francisco**...Dec. 23, '04 | A. H. Griswold. | A. G. Jones, 819 Rialto Building, San Francisco, Cal. |
| **Schenectady**.....Jan. 26, '03 | George H. Hill. | John R. Hewett, Gen. Elec. Co., Schenectady, N. Y. |
| **Seattle**.....Jan. 19, '04 | S. C. Lindsay. | E. A. Loew, University of Washington, Seattle, Wash. |
| **Spokane**.....Feb. 14, '13 | J. B. Fisken. | H. B. Peirce, Box 1436, Spokane, Wash. |
| **Toledo**.....June 3, '07 | George E. Kirk. | Max Neuber, Cohen, Freidlander & Martin, Toledo, O. |
| **Toronto**.....Sept. 30, '03 | D. H. McDougall. | H. T. Case, Continental Life Bldg., Toronto, Ont. |
| **Urbana**.....Nov. 25, '02 | Morgan Brooks. | I. W. Fisk, University of Illinois, Urbana, Ill. |
| **Vancouver**.....Aug. 22, '11 | E. M. Breed. | L. G. Robinson, 1003 Holden Building, Vancouver, B. C. |
| **Washington, D.C.**..Apr. 9, '03 | H. C. Eddy. | C. B. Mirick, 1302 N. Street, N.W., Washington, D. C. |

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Revised to March 1, 1914.

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| **Agricultural and Mechanical College of Texas**.....Nov. 12, '09 | D. B. Pickens. | E. C. Rack, A. & M. College, College Station, Tex. |
| **Arkansas, Univ. of**.....Mar. 25, '04 | S. S. McGill. | M. B. Roys, Univ. of Arkansas, Fayetteville, Ark. |
| **Armour Institute**.....Feb. 26, '04 | E. L. Nelson. | T. C. Bolton, Armour Inst. Tech., Chicago, Ill. |
| **Bucknell University**.....May 17,'10 | F. O. Schnure. | J. M. Hillman, Bucknell University, Lewisburg, Pa. |
| **California, Univ. of**.....Feb. 9, '12 | Charles Z. Yost. | L. E. Rushton, University of California, Berkeley, Cal. |
| **Cincinnati, Univ. of**.....Apr. 10, '08 | John H. Stewart. | J. S. Bishop. 2345 Kemper Lane, Cincinnati, Ohio. |
| **Clemson Agricultural College**.....Nov. 8, '12 | F. J. Jervey. | F. H. McDonald, Clemson College, S. C. |
| **Colorado State Agricultural College**.....Feb. 11, '10 | L. M. Klinefelter. | R. K. Havighorst. Colorado State Agricultural College, Fort Collins, Colo. |
| **Colorado, Univ. of**.....Dec. 16, 04 | L. E. Sweitzer. | Frank A. Redding, University of Colorado, Boulder, Colo. |
| **Highland Park College**..Oct. 11, '12 | E. B. Williams, | Ralph R. Chatterton, Highland Park College, Des Moines, Iowa. |
| **Iowa State College**.....Apr. 15, '03 | Earle G. Nichols. | F. A. Robbins, Iowa State College, Ames, Iowa. |
| **Iowa, Univ. of**.....May. 18, '09 | J. H. Scanlon. | A. H. Ford, University of Iowa, Iowa City, Ia. |
| **Kansas State Agr. Col.**..Jan. 10, '08 | L. O'Brien. | W. C. Lane, Kansas State Agric. Col., Manhattan, Kan. |
| **Kansas, Univ. of**.....Mar. 18, '08 | H. C. Hansen. | L. M. Bocker, Univ. of Kansas, Lawrence, Kansas. |
| **Kentucky State Univ. of**.Oct. 14, '10 | H. B. Hedges. | H. Tyler Watts, 315 East Maxwell Street, Lexington, Ky. |
| **Lafayette College**.....Apr. 5, '12 | G. P. Ellis. | V. A. Davison, Lafayette College, Easton, Pa. |
| **Lehigh University**.....Oct. 15, '02 | W. B. Todd. | G. Forster, Lehigh University, S. Bethlehem, Pa. |
| **Lewis Institute**.....Nov. 8, '07 | A. H. Fensholt, | Fred A. Rogers, Lewis Institute, Chicago, Ill. |
| **Maine, Univ. of**.....Dec. 26, '06 | C. M. Kelley. | E. L. Getchell, University of Maine, Orono, Maine. |
| **Michigan, Univ. of**.....Mar. 25, '04 | P. H. Evans. | E. T. Anderson, 608 Mary Court, Ann Arbor, Mich. |
| **Missouri, Univ. of**.....Jan. 10, '03 | H. B. Shaw. | E. W. Kellogg, 9 Engineering Building, Columbia, Mo. |
| **Montana State Col**.....May 21, '07 | Max W. Kenck. | J. A. Thaler, Montana State College, Boseman, Mont. |

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## LIST OF BRANCHES—Continued

| Name and when Organized | Chairman | Secretary |
|---|---|---|
| **Nebraska, Univ. of**.....Apr. 10, '08 | Olin J. Ferguson. | V. L. Hollister, Station A, Lincoln, Nebraska |
| **New Hampshire Col.**.....Feb. 19, '09 | | |
| **North Carolina Col. of Agr. and Mech. Arts**.....Feb. 11, '10 | Wm. H. Browne, Jr. | James Fontaine, West Raleigh, N. C. |
| **Ohio Northern Univ.**.....Feb. 9, '12 | George E. Boesger | Harry Restofski, Ohio Northern University, Ada, Ohio. |
| **Ohio State Univ.**.....Dec. 20, '02 | L. R. Yeager. | John M. Strait, Ohio State Univ., Columbus, Ohio. |
| **Oklahoma Agricultural and Mech. Col.**.....Oct. 13, '11 | A. P. Little. | Quentin Graham, 416 Hester Street, Stillwater, Okla. |
| **Oklahoma, Univ. of**.....Oct. 11, '12 | R. D. Evans. | L. J. Hibbard, Univ. of Oklahoma, Norman, Okla. |
| **Oregon Agr. Col.**.....Mar. 24, '08 | A. O. Manigold. | I. L. Olmstead, Oregon Agric. Col., Corvallis, Ore. |
| **Oregon, Univ. of**.....Nov. 11, '10 | C. R. Reid. | C. H. Van Duyn, Univ. of Oregon, Eugene, Oregon. |
| **Penn State College**.....Dec. 20, '02 | T. A. Jones. | A. D. Shultz, State College, Pa. |
| **Purdue Univ.**.....Jan. 26, '03 | C. F. Harding. | A. N. Topping, Purdue University, Lafayette, Ind. |
| **Rensselaer Poly. Inst.**....Nov. 12, '09 | E. D. N. Schulte. | W. J. Williams, Rensselaer Poly. Institute, Troy, N. Y. |
| **Rose Polytechnic Inst.**....Nov. 10, '11 | Charles F. Harris. | Claude A. Lyon, 1331 Liberty Avenue, Terre Haute, Ind. |
| **Rhode Island State Col.**..Mar. 14, '13 | Harry Webb. | P. M. Randall, Rhode Island State College, Kingston, R. I. |
| **Stanford Univ.**.....Dec. 13, '07 | G. O. Wilson. | L. M. Bussert, Stanford University, Cal. |
| **Syracuse Univ.**.....Feb. 24, '05 | W. P. Graham. | R. A. Porter, Syracuse University, Syracuse, N. Y. |
| **Texas, Univ. of**.....Feb. 14, '08 | Joseph W. Ramsey. | J. A. Correll. University of Texas, Austin, Tex. |
| **Throop College of Technology**.....Oct. 14, '10 | W. L. Newton. | A. W. Wells, Throop Poly. Institute, Pasadena, Cal. |
| **Vermont, Univ. of**.....Nov. 11, '10 | | |
| **Virginia, Univ. of**.....Feb. 9, '12 | Walter S. Rodman | Henry Woodman Clark, A. X. P. House, University, Virginia. |
| **Wash., State Col. of**....Dec. 13, '07 | M. K. Akers. | H. V. Carpenter, State Coll. of Wash., Pullman, Wash. |
| **Washington Univ.**.....Feb. 6, '04 | R. D. Duncan, Jr. | C. C. Hardy, Washington University, St. Louis, Mo. |
| **Washington, Univ. of**...Dec. 13, '12 | A. P. Newbury. | Charles A. Stanwick, Univ. of Washington, Seattle, Wash. |
| **Worcester Poly. Inst.**....Mar. 25, '04 | W. C. Blanchard. | Harry B. Lindsay, Worcester Poly. Inst., Worcester, Mass. |
| **Yale University**.....Oct. 03, 10 | R. G. Warner. | K. B. Jones, 136 Vanderbilt-Scientific, New Haven, Conn. |

Total, 47.

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# SECTION II

# PROCEEDINGS

of the

# American Institute

of

# Electrical Engineers

Papers, Discussions and Reports

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**PROCEEDINGS**

OF THE

**American Institute**

OF

**Electrical Engineers.**

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

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GEORGE R. METCALFE, Editor

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Vol. XXXIII **April, 1914** No. 4

## Institute Meeting in Pittsburgh April 9-10, 1914

The 293d meeting of the Institute will be held in Pittsburgh, Pa., on Thursday and Friday, April 9 and 10, 1914, under the auspices of the Committee on the Use of Electricity in Mines and the Pittsburgh Section.

The Institute recognizes the growing importance of the use of electricity in mines, and this will be the second special meeting devoted exclusively to the subject. The meeting held last year was very successful, and the indications are that the present meeting will be equally so.

The official headquarters of the Institute during the meeting will be at the Fort Pitt Hotel, and the technical sessions will be held in the English room of the hotel.

Members should register at Institute headquarters upon their arrival.

### PROGRAM

### Thursday, April 9

MORNING SESSION

1. *The Regulation of Electrical Installations in Mines.* Address by Wilfred Sykes, Chairman, Committee on Use of Electricity in Mines.
2. *Mine Duty Controllers*, by H. P. Reed, Cutler-Hammer Manufacturing Company, Milwaukee, Wis.

AFTERNOON SESSION

3. *Self-Contained Portable Electric Mine Lamps*, by H. O. Swoboda, Consulting Electrical and Mechanical Engineer, Pittsburgh, Pa.
4. *Discussion of Regulations for Electrical Installations in Mines.*

The following regulations have been printed and will be distributed to facilitate reference:

(a) German laws referring to electrical installations in mines.
(b) English laws referring to electrical installations in mines.
(c) Rules proposed by the Bureau of Standards, Washington, D. C.
(d) Rules proposed by American Mining Congress.
(e) Pennsylvania mining law, electrical section.

EVENING

6:30 P.M.

Informal Dutch dinner at the Fort Pitt Hotel; $1.25 per plate.

### Friday, April 10

MORNING SESSION

5. *The Development of the Electric Mine Locomotive*, by G. M. Eaton, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
6. *Mine Substations:*
   - I. *The Construction and Operation of Mine Substations*, by H. Booker, Pittsburgh-Buffalo Company, Pittsburgh, Pa.
   - II. *Motor-Generator Sets versus Synchronous Converters*, by Will M. Hoen, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

AFTERNOON SESSION

*Discussion of Regulations for Electrical Installations in Mines.*

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### Saturday, April 11

There will not be any technical sessions on Saturday, but arrangements will be made for visits to the various industrial plants in the Pittsburgh district. Further particulars regarding these visits will be announced at the meeting.

The prepared papers, Nos. 2, 3, 5 and 6 of the program, are printed in this issue of the PROCEEDINGS. Advance copies of these papers, and copies of the laws and regulations governing electrical installations in mines which are to be discussed at the meeting, may be obtained upon application to Mr. E. R. Spencer, Secretary Pittsburgh Section, 814 Frick Building, Pittsburgh, Pa.

## Joint Meeting in Washington, D. C., April 24-25, 1914

The 294th meeting of the Institute will be held in Washington, D. C., Friday and Saturday, April 24 and 25, 1914. This will be a joint meeting under the auspices of the Electrophysics Committee and the Washington and Baltimore Sections of the A.I.E.E., and the American Physical Society. There will be five papers presented on behalf of the A.I.E.E., as follows: *A Theory of Corona*, by Bergen Davis; *Some Investigations of Lightning Protection for Buildings*, by L. A. De Blois; *A Milliampere Current Transformer*, by Edward Bennett; *Some Simple Examples of Transmission Line Surges*, by W. S. Franklin; and *Solenoids*, by C. R. Underhill. These five papers are published in this issue of the PROCEEDINGS.

The program is as follows—Friday, April 24, morning: technical session, Physical Society and the A. I. E. E., conducted by the Physical Society. Afternoon: inspection of buildings of the Bureau of Standards and exhibition of laboratory equipment and methods. In addition to the apparatus of the Bureau there will be an exhibit of recently developed lecture, laboratory and research apparatus supplied by manufacturers, dealers, universities, and private individuals. This exhibit is under the auspices of the American Physical Society and will be similar to the successful annual exhibits of the London and French Physical Societies. Evening: joint technical session of the Physical Society and the A. I. E. E., conducted by the Electrophysics Committee, to be followed by a smoker.

Saturday, April 25, morning: technical session of the Physical Society and the A. I. E. E., conducted by Physical Society. Afternoon: visits to points of interest in Washington. Parties to be conducted by the Washington Section of the A. I. E. E.

Further details will be announced in the program to be issued before the meeting.

## Lectures on the Electromagnetic Theory

The Committee on Technical Lectures, with the approval of the Board of Directors, has arranged for two lectures to be given in the Engineering Societies Building in New York, by Dr. Michael I. Pupin, Professor of Electro-Mechanics at Columbia University. The subject of these lectures will be "The Electromagnetic Theory." Dr. Pupin will treat the subject from the points of view of the physicist and the electrical engineer, and will endeavor to differentiate these points of view. The first of these lectures will be given on Wednesday evening, April 29. The date of the second will be announced later.

## Report of Committee of Tellers on Nomination Ballots

*To the Board of Directors, American Institute of Electrical Engineers:*

Gentlemen: This committee has counted and canvassed, in accordance with Article VI of the Constitution, the nomination ballots received for officers

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of the Institute for 1914-1915. The result is as follows:

| | | |
|---|---|---|
| Total number of envelopes said to contain ballots received from the Secretary | | 1252 |
| Rejected on account of bearing no identifying name on outer envelope | 32 | |
| Rejected on account of having reached the Secretary's office after February 28 | 66 | |
| Envelopes received containing no ballots | 34 | 132 |
| Leaving as valid ballots | | 1120 |

These valid ballots were counted and the result is shown below:

FOR PRESIDENT

| | |
|---|---|
| P. M. Lincoln | 1036 |
| Scattering and blank | 84 |
| Total | 1120 |

(The scattering vote was divided among twenty candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR VICE-PRESIDENTS

| | |
|---|---|
| P. S. Hunting | 956 |
| N. W. Storer | 947 |
| Farley Osgood | 942 |
| W. S. Rugg | 103 |
| Scattering and blank | 412 |
| Total | 3360 |

(The scattering vote was divided among sixty-five candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR MANAGERS

| | |
|---|---|
| Frederick Bedell | 822 |
| E. J. Berg | 794 |
| B. Gherardi | 515 |
| J. H. Finney | 505 |
| A. S. McAllister | 491 |
| W. F. Wells | 455 |
| E. R. Hill | 338 |
| Charles Robbins | 51 |
| Scattering and blank | 509 |
| Total | 4480 |

(The scattering vote was divided among seventy-five candidates, each of whom received less than 3 per cent of the total vote. Detailed distribution of these votes is shown on the original tally sheets filed in the Institute offices.)

FOR TREASURER

| | |
|---|---|
| George A. Hamilton | 1000 |
| Scattering and blank | 120 |
| Total | 1120 |

Respectfully submitted,

J. H. PAYNE, *chairman.*
S. D. KUTNER,
ROGER MASON,
R. W. STAFFORD,
C. F. THOMPSON,
*Committee of Tellers.*

## Joint National Committee on Electrolysis

### FIRST MEETING

At the first meeting of the men now constituting the Joint National Committee on Electrolysis, held in New York on May 27, 1913, it was decided, owing to the fact that certain national associations had not at that time appointed representatives to serve on the committee, to have a temporary organization only, and await the meeting of the full committee before perfecting a permanent organization.

At this meeting the objects of forming such a national committee were set forth by different members. Mr. Bion J. Arnold was appointed temporary chairman, and he was requested to confer with the national organizations not at that time represented on the committee.

The temporary chairman appointed a Committee on Plan and Scope.

### SECOND MEETING

The second regular meeting of the Joint National Committee on Electrolysis was held in the rooms of the American Institute of Electrical Engineers, New York, on Wednesday, February 25, 1914.

There were present: Messrs. B. J. Arnold, temporary chairman; Calvert Townley, E. B. Katte, H. S. Warren, D. W. Roper, F. N. Waterman, Albert F. Ganz, W. J. Broder, A. S. Richey, Philip Torchio, L. L. Elden, Forest Towle, and Paul Winsor.

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Mr. B. J. Arnold was appointed permanent chairman of the Joint Committee.

In order that the work of the committee could be laid out, and a definite plan of action decided upon, it was voted to confirm the tentative appointment of the following members of a Plan and Scope Committee, whose duty it would be to prepare a tentative plan to be submitted to the Joint Committee for consideration: Messrs. Calvert Townley, chairman, representing the American Electric Railway Association; E. B. Katte, representing the American Railway Engineering Association; H. S. Warren, representing the American Telephone and Telegraph Company; D. W. Roper, representing the National Electric Light Association; F. N. Waterman, representing the American Institute of Electrical Engineers; A. F. Ganz, representing the American Gas Institute; W. J. Broder, representing the Natural Gas Association of America. This committee was requested to report to the Joint Committee on the following afternoon. Some discussion followed in regard to representation of various organizations upon the Joint Committee.

At the request of Chairman Arnold, Mr. Townley gave the following outline of the general scope of the committee for the benefit of those representatives who had been recently appointed and were therefore not present at the preliminary meeting in May, 1913:

Electrolysis controversies have in the past given rise to unnecessary and acrimonious disputes, and not infrequently have resulted in litigation between the corporations concerned. The usual procedure in disputes of this kind has been for each side to employ one or more electrical experts who generally disagree as to the cause of the trouble and the remedies therefor. The dispute sometimes gets into the newspapers, occasioning unpleasant notoriety, and resulting in more or less drastic municipal action by the city government concerned. Much of this could be avoided if a body such as this committee could be created which would consider broadly the questions covered by the controversy, without attempting to pass upon the questions at issue, but to report back to their respective organizations so that in time the committee would come to be recognized as a neutral body whose decisions would be authoritative, the same as the Standards Committee of the American Institute of Electrical Engineers in connection with matters of definition and standardization, which is a recognized authority that nobody ever attempts to question. With that end in view the American Institute of Electrical Engineers initiated the movement to organize a national body to consider the general subject, and agree upon any basic principles or methods of procedure to be followed in the case of electrolysis disputes. Now that the organization of such body has been accomplished, it remains for the committee to determine what lines of action to take.

Mr. Townley stated that in correspondence he had had with different people, the purpose of the committee was frequently misunderstood; that the impression prevailed in some cases that the committee was going to act as an arbitration board in controversies, and would tell what ought to be done, thereby taking the place of executives or the courts.

### Third Meeting

The third regular meeting of the Joint National Committee on Electrolysis was held in the rooms of the American Electric Railway Association, New York, on Thursday, February 26, 1914.

There were present: Messrs. B. J. Arnold, chairman; Calvert Townley, E. B. Katte, Philip Torchio, L. L. Elden, D. W. Roper, H. S. Warren, F. N. Waterman, Albert F. Ganz, Paul Winsor, E. B. Rosa, Forest Towle, and W. J. Broder.

The chairman reported that the invitation extended to the National

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Bureau of Standards to participate in the work of the Joint Committee had been accepted, and it was voted that the Bureau's representative, Dr. E.B. Rosa, be appointed secretary of the Joint Committee, and a member of the Plan and Scope Committee.

The Sub-Committee on Plan and Scope presented a preliminary report, and after discussion, the following resolution was adopted:

*Resolved*, That the chairman be authorized to appoint committees as informally recommended by the Plan and Scope Committee, to collect information as outlined in the report, and that the Committee on Plan and Scope be continued and requested to report further at the next meeting of the Joint Committee.

Chairman Arnold thereupon announced the appointment of the following committees: (1) Principles and Definitions, (2) Methods and Analyses of Surveys, (3) Foreign Practise, (4) Domestic Practise.

The following organizations are represented upon the Joint Committee: American Electric Railway Association, American Railway Engineering Association, National Electric Light Association, American Telephone and Telegraph Company, American Institute of Electrical Engineers, National Bureau of Standards, Natural Gas Association of America, and American Gas Institute.

## Second Midwinter Convention, New York, February 25-27, 1914

The second Midwinter Convention of the Institute, held this year under the auspices of the Electric Power Committee, opened on the morning of Wednesday, February 25, and closed with the session on Friday afternoon, February 27. The sessions were held in the auditorium of the Engineering Societies Building, New York. There were 16 papers and reports presented, several of the reports embodying separate short papers by different authors, each devoted to some subdivision of the main subject.

The total registered attendance at the convention was 472, of which 354 were members of the Institute. The attendance from outside of New York City and Brooklyn was 264.

President C. O. Mailloux called the first session to order at 10:20 a.m. Wednesday. In his introductory remarks he spoke of the success of the first Midwinter Convention, and the aid that the discussions on the subject of rating had given to the work of the International Electrotechnical Commission. He then spoke of the desirability of the reclassification of the technical committees of the Institute, which had resulted in the formation of the Electric Power Committee with its seven subdivisions. President Mailloux then introduced Chairman David B. Rushmore of the Electric Power Committee.

Chairman Rushmore's introductory address pointed out that the increasing specialization which was becoming necessary among electrical engineers would require still further subdivision and grouping of Institute committees to provide for the different kinds of electrical engineering work. He said that the proper field of the Electric Power Committee was essentially the field of the public utility, the generation, transmission and distribution of power. Some interesting curves were then projected on the screen, showing the rate of increase in the production of electrical apparatus, the extending use of electrical energy, the increasing consumption of coal, oil, copper and aluminum, and the decrease in the cost of electric power. Many other slides were shown, illustrating many types of apparatus for the production and utilization of electrical energy.

The remainder of the morning session was taken up with the report on the scope of the sub-committee on Engineering Data, and the report on the feasibility of an A. I. E. E. handbook.

The afternoon session was devoted to consideration of the six papers arranged by the Power Station subcommittee.

On Wednesday evening a meeting was held in the auditorium, under the

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auspices of the Executive Committee of the Committee on Organization of the International Electrical Congress, to arouse interest in the Congress to be held in San Francisco, September 13-18, 1915, during the Panama-Pacific Exposition. Mr. H. G. Stott, chairman of the Executive Committee, presided, and introduced Dr. C. P. Steinmetz, honorary president of the congress, who spoke of the achievements of past electrical congresses, and the steps in advance likely to be taken as a result of the interchange of ideas among electrical engineers of different countries at the coming congress.

Dr. William Rader, of Pottstown, Pa., presented an illustrated address on San Francisco and the exposition, and Mr. W. D'A. Ryan, of Schenectady, who is illuminating engineer for the exposition, described the unique lighting installations which have been arranged for the buildings and grounds. Mr. James A. Cruikshank, of New York, followed with a lecture, illustrated with stereopticon and moving pictures, on some scenic features of a trip to San Francisco. The last speaker, Mr. Paul M. Lincoln, described briefly some of the representative electric power developments of different types which visitors to the exposition would find in crossing the continent from the Atlantic to the Pacific.

On Thursday morning the Transmission session was held. The subcommittee report on *Problems of High-Tension Transmission Lines*, with four appendixes, was presented, and a paper by Mr. H. W. Buck on *Practical Operation of Suspension Insulators*. In the afternoon the session was devoted to the subjects of Power Generation and Economics. The papers considered were *The Economical Capacity of a Combined Hydroelectric and Steam Power Plant*, by Dr. C. T. Hutchinson, and *The Cost of Electricity at the Source*, by Mr. H. M. Hobart.

On Thursday evening, February 26, the only official social function of the convention was given at the Hotel Biltmore. It consisted of a subscription dinner-dance, under the joint auspices of the Institute and the Executive Committee of the Committee on Organization of the International Electrical Congress, to be held in San Francisco, 1915. Mr. Henry G. Stott, chairman of the Committee on Organization of the Congress, was toastmaster and brief addresses were made by him, by Dr. A. E. Kennelly, chairman of the Program Committee, and by Dr. Edw. B. Rosa, Honorary Secretary of the Congress. Dancing began at 10:30 p.m. and continued until about 2:00 a.m. About 350 members and guests participated, and the event was unanimously voted one of the most successful and enjoyable social meetings in the history of the Institute.

The session on Friday morning was devoted to the work of the sub-committee on Distribution. The report on *Distribution of Electrical Energy* was presented, with nine appendixes by different authors.

The closing session was held on Friday afternoon, and was devoted to the subject of Protective Apparatus. Dr. C. P. Steinmetz presented a paper on *Recording Devices*, and Professor E. E. F. Creighton a paper on *The Present Status of Aluminum-Cell Lightning Arresters*.

President Mailloux, in his closing remarks, said that the two Midwinter Conventions held in New York had been very successful, and that he believed they would from now on be regarded as a permanent feature of the program of the Institute's work.

## Dinner to Mr. Emil Huber-Stockar

Mr. Emil Huber-Stockar, of Zurich, Switzerland, for many years technical and managing director of the Oerlikon Works, and now engineer in charge for the Swiss Government of the electrification of the St. Gothard Tunnel, is in the United States. He arrived in New York March 7, for the purpose of visit-

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ing some of the important electrical developments in this country.

An informal dinner was given by President Mailloux at the Engineers Club, New York, on the evening of March 13, in honor of Mr. Huber, who is also president of the Swiss National Committee of the International Electrotechnical Commission. Those present at the dinner included Past-Presidents Carl Hering, Charles F. Scott, Frank J. Sprague and Lewis B. Stillwell, and Messrs. A. H. Armstrong, W. A. Del Mar, George Gibbs, H. M. Hobart, Cary T. Hutchinson, F. L. Hutchinson, H. A. Lardner, A. S. McAllister, William McClellan, W. S. Murray, Carl Schwartz, and N. W. Storer.

The occasion was very enjoyable to all and afforded an opportunity for some of the leading American authorities in electric railway engineering to meet the guest of honor and to discuss with him matters of mutual interest.

## Italian Society's New Periodical "L'Elettrotecnica"

The Associazione Elettrotecnica Italiana has made a new departure in issuing, from its Central Office in Milan, a periodical, *L'Elettrotecnica*, which appears on the 5th, 15th, and 25th of each month. This contains the Transactions of the Society, in addition to other matter. Number 1 of Volume I (Volume XVIII of the Transactions) was issued on February 5, 1914.

The following quotations from the announcement sent to members will indicate the scope of *L'Elettrotecnica:*

"Our periodical will still publish the Transactions of the Society, and, in addition, some original articles selected with the greatest care; it will therefore contain the best that is written in Italy in our field. But its purpose is especially that of giving a complete knowledge of whatever there may be in electrotechnology and in contiguous fields that is of interest for the culture of our members. To this end the periodical will publish ample and systematic notes on the more important articles, books, etc., published both in Italy and abroad, so as to enable the reader to follow the whole of Italian and foreign electrotechnical literature.

"It will contain also articles of general interest, in which the actual state of knowledge in reference to certain subjects will be summed up (see articles in the Transactions of 1913 on Diesel motors, on meters, on the electrochemistry of gases, etc.). In addition, it will contain general news, financial news, records of patents, etc."

The new publication has been launched with funds raised by subscription among the "collective" members (*i. e.*, companies and firms making an annual contribution to the funds of the Society). Individual members of the Associazione Elettrotecnica Italiana are invited to subscribe for the new periodical 5 lire ($1.00) annually for five years. It is the expectation that the publication will develop to such an extent as to become self-supporting.

## Directors' Meeting, New York, March 18, 1914

The regular monthly meeting of the Board of Directors of the Institute was held in New York on Friday, March 13, 1914.

There were present: President C. O. Mailloux, New York; Past-President Gano Dunn, New York; Vice-Presidents A. W. Berresford, Milwaukee, Wis., W.S. Murray, New Haven, Conn., H. H. Barnes, Jr. and Charles E. Scribner, New York; Managers N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J.Franklin Stevens, Philadelphia, Pa., William B. Jackson, Chicago, Ill., H. A. Lardner, San Francisco, Cal., William McClellan, New York, B. A. Behrend, Boston, Mass., L. T. Robinson, Schenectady, N. Y.; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

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The action of the Finance Committee in approving monthly bills amounting to $11,402.00 was ratified.

Upon the recommendation of the Finance Committee the appropriation of the Standards Committee for the current year was increased from $250 to $1,000, the increase being necessary to enable the committee to carry through its work of revising the Standardization Rules, which is now nearing completion.

Upon the recommendation of the Meetings and Papers Committee the Electric Illumination Committee was authorized to participate in a joint session at the convention of the Illuminating Engineering Society at Cleveland, Ohio, during the week beginning September 21, 1914.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred three members of the Institute to the grade of Fellow and three to the grade of Member, elected one applicant as a Fellow, seven as Members and 86 as Associates, and ordered the enrolment of 55 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

Upon the invitation of the President of the American Electric Railway Association, President Mailloux was authorized to appoint three representatives of the Institute upon a proposed Joint National Committee on Overhead Line Construction, the committee to be composed of three members of each of the following organizations: American Electric Railway Engineering Association, National Electric Light Association, American Railway Engineering Association, American Telephone and Telegraph Company, American Institute of Electrical Engineers.

Resolutions were adopted as a tribute to the memory of Past-President Edwin J. Houston, whose death occurred on March 1, 1914.

Announcement was made of the death on March 12 of Mr. George Westinghouse, and the President was authorized to appoint a delegation to represent the Institute at the funeral services.

The report of the Committee of Tellers giving the result of its canvass of the nomination ballots cast for the offices to be filled at the next annual election was read. The Board then selected from the Tellers' report its list of Directors' Nominees for the offices falling vacant, as required by the Constitution. These nominees are: For president, Paul M. Lincoln, Pittsburgh, Pa.; for vice-presidents, F. S. Hunting, Fort Wayne, Ind., N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J.; for managers, Frederick Bedell, Ithaca, N. Y., Bancroft Gherardi, New York, John H. Finney, Washington, D. C., A. S. McAllister, New York; for treasurer, George A. Hamilton, Elizabeth, N. J.

## A. I. E. E. Meeting in New York March 13, 1914

The 292d meeting of the Institute, under the auspices of the Telegraphy and Telephony Committee, in which the Institute of Radio Engineers participated with the A. I. E. E., was held in the auditorium of the Engineering Societies Building, New York, on the evening of March 13, 1914.

President C. O. Mailloux called the meeting to order at 8:20 p.m., and asked Mr. Cloyd Marshall to preside as acting chairman of the Telegraphy and Telephony Committee, in place of Chairman F. F. Fowle, who was unable to be present. Mr. Marshall presided during the presentation and discussion of the two A. I. E. E. papers.

Mr. W. Lee Campbell first presented his paper, *Traffic Studies in Automatic-Switchboard Telephone Systems*, and was followed by Mr. M. H. Clapp, whose paper was entitled *A Comparison of the Telegraph with the Telephone as a Means of Communication in Steam Railroad Operation*. The discussion of these two papers was participated in by Messrs. William Mavor, Jr., W. E. Harkness, R. N. Hill, S. P. Grace and J. B. Taylor.

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When this discussion had closed, President Mailloux called upon Mr. John Stone Stone, vice-president of the Institute of Radio Engineers, to take charge of the meeting. Mr. E. E. Mayer then presented his paper on "The Goldschmidt System of Radiotelegraphy," describing the important features of the Goldschmidt high-frequency generator and "tone-wheel" and the results that had been attained in transmitting messages from Eilvese, near Hanover, Germany, to Tuckerton, New Jersey. Mr. Mayer's paper was discussed by Messrs. R. H. Marriott, E. F. W. Alexanderson, Dr. Lee De Forest, Dr. M. I. Pupin and Mr. John Stone Stone.

The meeting was then adjourned to the rooms of the Institute on the tenth floor, where light refreshments were served to the members of the two societies and their guests.

## Recommended for Transfer, March 10, 1914

The Board of Examiners, at its regular monthly meeting on March 10, 1914, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

### To the Grade of Fellow

FECHHEIMER, CARL J., Crocker-Wheeler Co., Ampere, N.J.

### To the Grade of Member

BOWLING, VICTOR S., Electrical Engineering and Contracting; President, Shearer Electrical Construction Co., Mexico City, Mexico.

CORNELIUS, MARTIN, Electrical Engineer, Switchboard Div., Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

RYDER, MALCOLM P., Engineer, Witherbee Igniter Co., Springfield, Mass.

## Transferred to the Grade of Fellow February 26 and March 18, 1914

The following were transferred to the grade of Fellow of the Institute at the meetings of the Board of Directors on February 26 and March 13, 1914.

*Transferred February* 26, 1914

BAUM, F. G., Consulting Engineer; Chief Engineer Hydraulic Construction, and General Superintendent Construction, Pacific Gas & Electric Co., San Francisco, Cal.

*Transferred March* 13, 1914

ELSDON-DEW, W., Consulting Electrical & Mechanical Engineer, Central Mining & Investment Corporation, Johannesburg, S. Africa.

HENDERSON, S. E. M., Electrical Engineer, Canadian General Electric Co., Peterboro, Ont.

WILDER, CLIFTON W., Electrical Engineer, Public Service Commission, New York, N. Y.

## Fellows Elected February 26 and March 18, 1914

*Elected February* 26, 1914

WIRT, CHARLES, President, Wirt Co., Germantown, Philadelphia, Pa.

*Elected March* 13, 1914

VON BLUCHER, F. A., Electrical and Mechanical Engineer, A. E. G. Cia. Mexicana de Electricidad, S. A., Mexico City, Mexico.

## Transferred to the Grade of Member February 26 and March 18, 1914

The following Associates were transferred to the grade of Member of the Institute at the meetings of the Board of Directors on February 26 and March 13, 1914.

*Transferred February* 26, 1914

LITTLE, ARLINGTON P., Associate Professor of Electrical Engineering, Oklahoma A. & M. College, Stillwater, Okla.

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PYLE, CLARENCE G., District Sales Agent, Standard Underground Cable Co., Los Angeles, Cal.

*Transferred March* 13, 1914

ADAMS, JULIAN, Assistant Electrical Superintendent, Pacific Electric Railway Co., Los Angeles, Cal.

ADLER, M. G., Chief Draftsman Los Angeles Aqueduct Power, Los Angeles, Cal.

BERTHOLD, MARTIN, Chief Engineer, Imperial Electric Co., Akron, Ohio.

## Members Elected February 26 and March 13, 1914

*Elected February* 26, 1914

BURROWS, CHARLES W., Associate Physicist, Bureau of Standards, Washington, D. C.

KINGSLAND, R. L., Superintendent, Power and Mechanical Dept., Consolidation Coal Co., Fairmont, W. Va.

LOWE, H. LELAND, Chief Engineer, National Light & Power Co., 1148 Pierce Bldg., St. Louis, Mo.

POWERS, A. RAYMOND, Professor of Electrical Engineering, Clarkson College of Technology, Potsdam, N. Y.

*Elected March* 13, 1914

BUCHACA, EMILIO J., District Engineer, New York Telephone Co., Syracuse, N. Y.

CAROLAN, EDGAR A., General Electric Co., 30 Church St., New York, N.Y.

COOKE, M. T., JR., Commercial Engineer, General Electric Co., Philadelphia, Pa.

FITZGERALD, FRANCIS A. J., Consulting Engineer, FitzGerald and Bennie Laboratories, Niagara Falls, N. Y.

PORTER, J. BENTON, Electrical Engineer and Salesman, General Electric Co., Philadelphia, Pa.

RANDOLPH, HARRY FITZ, President, Randolph-Means Co., Pittsburgh, Pa.

VOSMAER, A., Electrochemical Engineer; Ozone Expert; Brooklyn. N. Y.

## Associates Elected February 26 and March 13, 1914

**Elected February 26, 1914**

ALLEN, LESLIE W., Sales Engineer, Westinghouse Electric & Mfg. Co., 712 Paulsen Bldg., Spokane, Wash.

ANDERSON, ARVID R., Electrical Engineer, Jeffrey Manufacturing Co.; res., 239 E. 19th Ave., Columbus, O.

ARMSTRONG, R. S., Assistant Toll Manager, Chicago Telephone Co., res., 4406 N. Greenview Ave., Chicago, Ill.

ATWOOD, E. H., Electrical and Mechanical Engineer, Vacuum Oil Co.; res., 607 Putnam St., Olean, N. Y.

BARTLETT, CHENRY C., Superintendent, Southern Sierras Power Co., Corona, Cal.

BARTON, F. S., Electrical Engineer, Nunda, N. Y.

BECK, WILLIAM HENRY, Electrician Foreman, Cleveland Construction Co., 134 S. Clinton St., Baltimore, Md.

BLACK, CHARLES DAY, Assistant Electrical Engineer, Research Laboratory, General Electric Works; res., 239 Second St., Pittsfield, Mass.

BONVOULOIR, LIONEL, Draftsman for Superintendent of Equipment, Bay State Street Ry. Co.; res., 394 Marlboro St., Boston, Mass.

BOPP, C. D., Engineer Salesman, General Electric Co., Monadnock Building, Chicago, Ill.

BRACKETT, HAROLD H., Engineering Dept., New York Telephone Co., New York; res., 407 Berkeley Ave., Bloomfield, N. J.

BREWBAKER, MILO W., Electrical Foreman, Isthmian Canal Commission, Gatun, Canal Zone.

BUCHOLZ, CARL D., Inspector of Distribution, Philadelphia Electric Co.; res., 2520 W. 9th St., Philadelphia, Pa.

BURGOON, CHARLES ELI, Inspector, Isthmian Canal Commission, Washington, D.C.

BURNHAM, G. B., Sales Agent, General Electric Co., San Francisco; res., 2801 Russell St., Berkeley, Cal.

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CARR, E. C., Student, University of Washington; res., 4760 21st Ave. N. E., Seattle, Wash.

CHERNYSHOFF, ALEXANDER, Electrical Electrical Engineer, Polytechnic Institute of St. Petersburg, St.Petersburg, Russia.

CLEMENT, MILLARD F., Inspector, McHenry & Murray, Engineers; res., 11 Howe Ave., New Rochelle, N. Y.

CRAWFORD, DONALD KAHR, Signal Draftsman, A. T. &. S. F. Ry. Co.; res., 1012 Tyler St., Topeka, Kans.

DIETRICH, FRED W., Assistant Engineer, Eugene Water Board, Eugene, Ore.

DYER, ALEXANDER B., Local Manager, Central Mexico Light & Power Co., San Miguel Allende, Guanajuato, Mexico.

DYER, WALTER H., Instructor of Electrical Engineering, Billings Polytechnic Institute, Billings, Mont.

EBY, EARL E., Electrical Engineer, Westinghouse Electric & Mfg. Co., E. Pittsburgh, res., 527 Holmes St., Wilkinsburg, Pa.

EMBREE, C. J., Assistant Engineer, Isthmian Canal Commission, Culebra, Canal Zone.

FAWCETT, CHARLES D., Instructor in Electrical Engineering, University of Pennsylvania; res., 4323 Walnut St., Philadelphia, Pa.

FENLEY, WILLIAM H., Superintendent Telephones and Signals, Panama R. R., Cristobal, Canal Zone.

FLOWERS, JOHN B., Electrical Engineer Underwood Typewriter Co., New York; res., 219 Linden Ave., Brooklyn, N. Y.

GALBRAITH, FRED EARLEY, Plant Dept., American Telephone & Telegraph Co., 24 Walker St., New York N. Y.

GARTHORNE, G. E., Operating and Maintenance Dept., Pacific Gas & Electric Co.; res., 1200 Taylor St., San Francisco, Cal.

GFRORER, ALBERT H., Designing Engineer, C. W. Hunt Co., West New Brighton, N. Y.

GILES, G. STEWART, Inspector, Associated Factory Mutual Fire Insurance Cos.; res., Central Y.M.C.A., Philadelphia, Pa.,

GOETZ, WERNER W., Sales Engineer, Cutler-Hammer Mfg. Co.,1201 Chestnut St., Philadelphia, Pa.

HARVEY, RANALD JOHN, Second in charge of A. C. Testing Dept., Dick, Kerr & Co., Ltd.; res., 3 Westgate Terrace, Whitstable, Kent, England.

HASTINGS, RUSSELL, Purchase Clerk, Edison Electric Illuminating Co., Boston; res., 79 St. Paul St., Brookline, Mass.

HEATH, H. T., Commercial Engineer, Railway & Lighting Sales Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh; res., 1116 Rebecca St., Wilkinsburg, Pa.

HORTON, BRYSON D., General Manager, Detroit Fuse & Mfg. Co.; res., 146 Calvert Ave., Detroit, Mich.

JAMES, HAMILTON, Electrical Engineer, Stuart & James, Bluefield, W. Va.

JENSEN, JAMES OLIVER, Secretary and General Manager, Los Gatos Telephone Co., Los Gatos Cal.

JETER, FLETCHER A., Superintendent Substations, Spokane Inland Empire Ry. Co., Spokane, Wash.

JOHNSTON, A. L., Electrical Engineer Luzerne Co. Gas & Electric Co.; res., 21 Centre Avenue, Plymouth, Pa.

JONES, FREDERICK S., Student, University of Maine, Orono, Maine.

KAYLOR, PAUL P., Chief Electrician, Olympic Portland Cement Co.; res., 2737 Humbolt St., Bellingham, Wash.

KEGERREIS, ROY, Instructor in Electrical Engineering, University of Pennsylvania, Philadelphia, Pa.

KINSMAN, R. E., Electrical Engineer, 348 West 87th St., New York, N. Y.

KLOPP, J. B., Student Engineer, Testing Dept., General Electric Co.; res., 602 Union St., Schenectady, N. Y.

KRIEGSMANN, ARNOLD E., Electrical Engineer, Lighting Engineering Dept. General Electric Co., Schenectady, N. Y.

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KRONE, ROBERT HOWARD, Draftsman, Bullock Electric Mfg. Co.; res., 2278 Harris Ave., Norwood, Ohio.

KUEHNE, JOHN HERBERT, Electrical Engineer, Buffalo Electric Co.; res., 179 Timon St., Buffalo, N. Y.

KUNKEL, CHARLES D., Sales Engineer, Westinghouse Electric & Mfg. Co., 712 Paulsen Bldg., Spokane, Wash.

KURIE, C. W., JR., Operating Dept., Colorado Springs Light, Heat & Power Co., 116 E. Washington St., Colorado Springs, Colo.

KURTZ, FREDERIC W., Ballistic Division, E. I. duPont deNemours Powder Co., Henry Clay; res., Claymont, Del.

LARSEN, C. J., Chief Engineer, Consolidated Telephone Co., Hazleton, Pa.

LIGHTBODY, JAMES N., Electrical Draftsman, City Electric Light Department, Calgary, Alta.

MACMURCHY, HERBERT GRANVILLE, Chief Electrical Draftsman, Toronto Power Co.; res., 1537 Duffern St., Toronto, Ont.

MARTIN, W. H., Engineering Dept., American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

MCCLELLAN, L. N., Junior Engineer, U. S. Reclamation Service; res., Y. M. C. A. Bldg., Phoenix, Ariz.

MCGUIRE, WILLIAM P., Traveling Electrician, C. R. I. & P. Ry.; res., 319 S. Lombard Ave., Oak Park, Ill.

MEYERHERM, CHARLES F., Assistant to Consulting Electrical Engineer, Stevens Institute of Technology, Hoboken, N. J.; res., 833 Gates Ave., Brooklyn, N. Y.

NIMS, STUART A., Assistant Engineer, New Hampshire Public Service Commission, Concord; res., 81 Park Ave., Keene, N. H.

NOLTE, R. W., Wireman, Isthmian Canal Commission, Miraflores, Canal Zone.

OVEROCKER, RANDALL HAYNER, Engineering Assistant, New York Telephone Co., New York, N. Y.; res., Hasbrouck Heights, N. J.

PARKER, R. I., Electrical Engineer, Lighting Engineering Dept., General Electric Co., Schenectady, N. Y.

PARSONS, D. E., Salesman, Westinghouse Electric & Mfg. Co., 1714 Union Bank Bldg., Pittsburgh, Pa.

PEARSON, G. ALLEN, Special Electrical Testing, Crocker-Wheeler Co., Ampere; res., 182 N. 16th St., E. Orange, N. J.

RICHEY, A. L., Engineering Assistant, New York Telephone Co.; res., 224 E. 15th St., New York, N. Y.

SAMS, FRED V., Draftsman, Allis-Chalmers Co., Milwaukee, Wis.

SCHMAUDER, W. G., Superintendent of Power, Texas Power & Light Co., Waco, Texas.

SCHUMAN, ERNEST SCOTT, Graduate Student in Applied Science, Harvard University; res., 5 Carver St., Cambridge, Mass.

SCRIVEN, E. O., Electrical Engineer, Western Electric Co., 463 West St., New York, N. Y.

SIMONSON, G. M., Electrical Draftsman, State Department of Engineering, Sacramento; res., 1524 Alameda Ave., Alameda, Cal.

SMITH, DWIGHT L., Power Supervisor, Chicago Elevated Railroads; 4631 Indiana Ave., Chicago, Ill.

STAIR, JACOB, JR., Engineer, General Engineering Div., Westinghouse Electric & Mfg. Co.; res., East Liberty Y. M. C. A., Pittsburgh, Pa.

STERN, M. R., General Manager, South Pittsburgh Light & Power Co., Adams Bldg., Chattanooga, Tenn.

STEWART, C. R., Electrical Engineer, General Electric Co.; res., 68 Springside Ave., Pittsfield, Mass.

SUGIYAMA, KOICHI, Electrical Engineer, Inawashiro Hydro-Electric Co. Ltd., Marunouchi, Tokyo, Japan.

SWENSON, THEODORE, JR., Engineering Dept., St. Paul Southern Electric Ry.; res., 256 Goodrich Ave., St. Paul, Minn.

TAYLOR, HORACE V. S., Electrical Engineer, Westinghouse Electric & Mfg. Co.; res., Simen Ave., N. S., Pittsburgh, Pa.

TOWN, THOMAS, Resident Engineer, Power House, Rapid City, Manitoba.

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VANNORMAN, C. P., Resident Engineer Toronto & York Radial Railway Co.; res., 282 Carlton St., Toronto, Ont.

WALKER, J. P. Service Engineer, Westinghouse Electric & Mfg. Co.; res., 78 W. North Ave., Atlanta, Ga.

WALTER, R. E., Detail Draftsman, Litchfield Mfg. Co.; res., 532 Dawson St., Waterloo, Ia.

WASHBURN, FRANK S., President, Alabama Power Co., Stahlman Bldg., Nashville, Tenn.

WENK, MORRIS, Draftsman, Stockton Iron Works; res., 17 N. California St., Stockton, Cal.

WILLIAMS, RALPH, Assistant Chief, Electrical Dept., N. J. Zinc Co. (of Pa.), Palmerton; res., 201 Centre St., Slatington, Pa.

YABE, TOMOWO, Engineer, Keihau Electric Railway Co., Osaka, Japan.

ZIEHN, ROBERT S., Switchboard Repairman, Chicago Telephone Co.; res., 172 Eugene St., Chicago, Ill.

Total 86.

**Elected March 13, 1914**

ATKINSON, OLIVER C., General Foreman, 1st Division Electricians, Isthmian Canal Commission, Gatun, C. Z.

BAHLMANN, ERWIN FELIX, Chemist, United States Glue Co., Otjen; res., 693 Layton Blvd., Milwaukee, Wis.

BARKER, CHARLES M., Chief Estimating Engineer, Standard Plunger Elevator Co., Worcester, Mass.

BEAVER, J. LYNFORD, Instructor in Electrical Engineering, Drexel Institute, Philadelphia; res., Llanerch, Pa.

BLAIR, FRANK W., Chief Draftsman, German American Stoneware Works, 50 Church St., New York, N. Y.

BOYER, ROBERT HOGARTH, Transformer Commercial Dept., General Electric Co.; res., Room 352, Y. M. C. A., Pittsfield, Mass.

BRADLEY, H. C., Construction Dept., Fort Wayne Electric Works of General Electric Co., Fort Wayne, Ind.

BROE, A. L., Commercial Engineering Dept., Edison Lamp Works, General Electric Co., Harrison, N. J.; res., 214 E. 61st St., New York, N. Y.

BROWNELL, R. A., Engineering Dept., Lincoln Gas & Electric Light Co., Lincoln, Nebr.

BRUNT, ALBERT, Electrical Engineer, Westinghouse Electric & Mfg. Co.; res., 310 Denniston Ave., Pittsburgh, Pa.

BUNDY, E. S., Construction Foreman, Niagara, Lockport & Ontario Power Co., Solvay, N. Y.

CHAPP, JOHN J., Assistant Chief Electrician, Swift & Co., U. S. Yards; res., 6543 S. Paulina St., Chicago, Ill.

CHRISTENSEN, C. P., Electrician, 218 Fourth Ave. W., Kalispell, Mont.

CODE, A. G., Switchboard Engineer, Canadian Westinghouse Co., Hamilton, Canada.

COWLES, R. ROY, Assistant Superintendent Electric Distribution, Pacific Gas & Electric Co.; res., 514 Fairbanks Ave., Oakland, Calif.

COX, WILLIAM NORRISS, Engineering Dept., General Electric Co., Philadelphia, Pa.

CULLY, WILLIAM L., Electrical Engineer Cutler-Hammer Mfg. Co., 144th St. & Southern Boulevard, New York, N. Y.

CURTNER, D. LINDER, Purdue University; res., 1028 Heath St., Lafayette, Ind.

DIESEM, L. C., Railway & Traction Engineering Dept., General Electric Co. Schenectady, N. Y.

DIMOCK, ARTHUR H., City Engineer, City Hall, Seattle, Wash.

DINTER, H. A., Electrician, Hico Electric Light & Power Co., Hico, Texas.

DOWEY, T. L., Telephone Engineer, Western Electric Co.; res., 234 W. 21st St., New York, N. Y.

DRESSER, SIDNEY R., Power Engineer, United Electric Light & Power Co., 1170 Broadway, New York, N. Y.

ELLWANGER, EDWARD F., Tester & Repairer, General Electric Co.; res., 1829 Fremont St., Chicago, Ill.

ELLIOTT, SAMUEL S., Electrical Foreman, Isthmian Canal Commission, Corozal, C. Z.

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ERDMANN, MORRIS H., Salesman, Electric Controller & Mfg. Co., Room 1563, 50 Church St., New York, N. Y.

FILKINS, EARL R., Testing Engineer, Illinois Northern Utilities Co.; res., 820 N. Crawford Ave., Dixon, Ill.

FOERSTERLING, FRED J., Superintendent Electric Meter Dept., Central Illinois Light Co., 318 S. Jefferson St., Peoria, Ill.

FOOTE, ALBERT HIRAM, Electrician, Musolaphone Corporation, Room 1609, 110 S. Dearborn St., Chicago, Ill.

FUKAGAWA, KEECH, Chief Engineer, Arisan Sagiosho Mills, Kagi, Formosa, Japan.

GAINES, S. NEWTON, Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

GARDINER, THOMAS BRADFORD, Electrical Material Foreman, Isthmian Canal Commission, Miraflores Locks; res., Paraiso, C.Z.

GARRETT, J. H., Electrical Foreman, Isthmian Canal Commission, Corozal, C. Z.

GIROUX, ROY M., Designing Engineer, D. C. Engineering Dept., General Electric Co., Schenectady, N. Y.

GLASER, LEWIS TIER, Municipal Light Plant; res., 552 E. 117th St., Cleveland, Ohio.

GOODMAN, M. D., Salesman, Electric Controller & Mfg. Co., 50 Church St., New York, N. Y.

GRAUER, JACOB G., Draftsman, Department of City Transit; res., 3203 Engleside Place, Philadelphia, Pa.

GRAYBILL, JOHN HOLDEMAN, Electrical Inspector, Jones & Laughlin Steel Co.; res., 3617 Dawson St., Pittsburgh, Pa.

HAGENLOCHER, ERNEST, Electrical Engineering, J. G. White Engineering Corp., 43 Exchange Place, New York, N. Y.

HAGUE, FLOYD T., Engineer, Westinghouse Electric & Mfg. Co.; res., 7532 Hamilton Ave., Pittsburgh, Pa.

HAINES, J. M., Vice-President, Commercial Motor Car Co.; res., 162 Hanover St., Wilkes-Barre, Pa.

HANSON, E., City Electrical Engineer and Street Railway Superintendent, City Hall, Saskatoon, Sask.

HARGER, CHARLES, Superintendent, Peninsular Power Co., Iron Mountain, Mich.

HATCH, RALPH S., Power Station Designer, Sargent & Lundy; res., 3539 Grand Blvd., Chicago, Ill.

HIRDLER, FAIRBANKS CARL, Supervisor of Traffic, Pioneer Telephone & Telegraph Co.; res., 927 W. 10th St., Oklahoma City, Okla.

HOLLINGSWORTH, G. R., General Foreman Electrical & Mechanical Installation, Isthmian Canal Commission, Pedro Miguel, C. Z.

HOLMES, HOWARD A., Expert Aid, Public Works Dept., U. S. Naval Station, Newport, R. I.

JACKSON, NEWTON, Cadet Engineer, U. G. I. Company, Broad & Arch Sts., Philadelphia, Pa.

JEFFERSON, W. H., Electrical Engineer, Cutler-Hammer Mfg. Co.; res., Flat 3, 183-14th St., Milwaukee, Wis.

KEMP, H. D., Electrical Engineer, Foreign Dept., Mead-Morrison Mfg. Co., E. Boston; res., 108 Mt. Vernon St., W. Roxbury, Mass.

KENDALL, ROBERT THRIFT, Construction, Eastern Michigan Power Co., Jackson, Mich.; res., 2360 Glenwood Ave., Toledo, Ohio.

KING, G. ALLAN, Assistant Superintendent of Shops, Public Service Railway, Newark; res., 169 Park Ave., East Orange, N. J.

KING, ROBERT P., Electrical Engineer, Public Service Railway Co., Newark; res., 104 Elm St., Montclair, N. J.

KLIPPEL, FRANK H., Meter Tester, Nevada-California Power Co., Tonopah, Nev.

KOLLOCK, G. J., Engineering Dept., Georgia Railway & Power Co.; res., 237 N. Jackson St., Atlanta, Ga.

LEE, COLIN KINGSLEY, Manager, Pike Co. Electric Light & Power Co., Bowling Green, Mo.

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LEEPER, J. B., Engineer in charge, Electric Transmission Tower Dept., American Bridge Co., 1432 Frick Building, Pittsburgh, Pa.

MAN, GEORGE A., Sales Dept., Cleveland Electric Illuminating Co.; res., 1923 Aiken Ave., Cleveland, Ohio.

MAXWELL, MARCUSWELL, Student Engineer, General Electric Co., Union National Bank, Schenectady, N. Y.

McDONALD, ELBERT CHARLES, Foreman, Telegraph & Signal Dept., Panama R. R., Colon; res., Pedro Miguel, C. Z.

McMILLAN, FRED O., Student Engineer, General Electric Co., Schenectady, N. Y.

MOORE, JACK, Electrical Operator, Canadian Klondyke Power Co., Dawson, Y. T.

MUNROE, RUSSELL B. Electrician, Phoenix Construction Co., Bingham Canyon; res., 754 North 1st St. East, Provo, Utah.

NEWTON, W. L., Student, Electrical Engineering, Throop College of Technology; res., 470 Prescott St., Pasadena, Cal.

NUTT, ARTHUR M., Assistant General Superintendent, Aluminum Co. of America, Pittsburgh, Pa.; res., Massena, N. Y.

PARKER, G. CAMERON, Technical Editor, ***Motor Magazine;*** res., 29 Dorval Road, Toronto, Ont.

PERRY, O. M., Superintendent, Windsor Hydro-Electric System, Windsor, Ontario.

PHILLIPS, C. E., Estimator, Allis-Chalmers Mfg. Co.; res., 4923 Linden St., Norwood, Ohio.

PRESCOTT, R. D., Inspector General, Telegraph & Telephone, Republic of Panama, Post Office Building, Panama, Panama.

REYNOLDS, OSWALD B., Operating Engineer, Power Station, Waipori Falls, Otago, New Zealand.

RINEHART, ORVILLE B., Electrical Engineer, Ft. Wayne Electric Works of General Electric Co.; res., 3141 Broadway, Ft. Wayne, Ind.

ROBINSON, PERCY W., Induction Motor Engineering Dept., General Electric Co.; 311 Craig St., Schenectady, N. Y.

SCHWEGMANN, JOSEPH F., Electrical Engineer, Construction Engineering Dept., Texas Power & Light Co., Capital Hotel, Tyler, Texas.

SHANKLIN, SHELBY, Commerical Engineer, General Electric Co.; res., 1029 Spruce St., Philadelphia, Pa.

SHAW, CLAUDE L., Operating Dept., Northern California Power Co., Manton, Calif.

SHOESTER, GEORGE W., Foreman of Electricians, Pennsylvania Railroad Co., Camden, N. J.

SJOBLOM, A. T., General Electrical Foreman, Isthmian Canal Commission, Corozal, C. Z.

SYLVESTER, WILLIAM, Draftsman, Allis-Chalmers Mfg. Co.; res., 403-64th Ave., West Allis, Wis.

THOMAS, BENJ. F., JR., Assistant Engineer, Electric Company of Missouri, Webster Groves; res., Kirkwood, Mo.

TRAMM, WILLIAM H., Teaching Assistant, University of Michigan, Ann Arbor, Mich.

WARNER, EDWARD E., Engineering Salesman, Aluminum Co. of America, 513 Metropolitan Bank Building, Washington, D. C.

WATSON, H. L., Electrical Engineer, Meter & Instrument Dept., General Electric Co., West Lynn, Mass.

WEISS, F. C., Inspector of Transmission line construction, Alabama Power Co., Birmingham, Ala.

WELCH, GEORGE R., Electrical Foreman Isthmian Canal Commission, Corozal, C. Z.

WELLS, C. J., Distribution Dept., Milwaukee Electric Railway & Light Co.; res., 212-13th St., Milwaukee, Wis.

ZENGERLE, JOSEPH C., Engineering Inspector, Bureau of Fire Alarm Telegraph, Fire Department, New York; res., 33 Crosby Ave., Brooklyn, N. Y.

Total 86

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## Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before April 30, 1914.

Avery, T., Jr., Srinagar, India.
Becker, E. L., Ampere, N. J.
Benedict, E. G., New Haven, Conn.
Bentley, R. O., (Member) Hackensack, N. J.
Boyden, L. L., Corozal, C. Z.
Britt, O. L., Stillwater, Okla.
Bundy, O. H., Washington, D. C.
Carpenter, R. H., New York, N. Y.
Chu, F. I., Madison, Wis.
Chung, N. P., Madison, Wis.
Ely, F. H., Corozal, C. Z.
Fay, J. L., (Fellow), St. Louis, Mo.
Freeman, J. S., Philadelphia, Pa.
Hellenthal, J., Seattle, Wash.
Hiss, F. I., Jr., (Member), Ampere, N.J.
Holz, M. H., Philadelphia, Pa.
Jobson, A. J., Brigham City, Utah.
Keller, L. H., Chicago, Ill.
Kimball, J. M., Providence, R. I.
Lansing, F. M., Omaha, Neb.
Larkin, J. E., Pittsfield, Mass.
Mans, G. C., Boston, Mass.
Marsh, F. L., Chicago, Ill.
Mercer, J. M., Pittsburgh, Pa.
Millan, W. H., St. Louis, Mo.
Mitrovitch, M. S., Drum, Calif.
Moore, I. W., Des Moines, Iowa.
More, C. H., New York, N. Y.
Neus, H. E., New York, N. Y.
Nichols, G. B., (Member), Albany, N.Y.
Owens, R., Chicago, Ill.
Paul, C. W., New York, N. Y.
Perry, B. L., Edmonton, Alta.
Richards, W. E., Toledo, Ohio.
Schirtzinger, F. E., Middletown, Ohio.
Schuler, L., Berlin, Germany.
Shire, H. I., Detroit, Mich.
Silver, N. H., Seattle, Wash.
Smith, H. R., Toronto, Ontario.
Wilcox, R. B., Pittsburgh, Pa.
Wilson, A., Montreal, Quebec.
Wright, C. F., Des Moines, Iowa.
Total 42.

## Students Enrolled February 26 and March 18, 1914

ENROLLED FEBRUARY 26, 1914

6320 Green, C. H., Stanford University.
6321 Haas, P. G., Wentworth Institute.
6322 Stewart, J. H., Univ. of Cinn.
6323 Anderson, C. H., Colorado College.
6324 McCoy, W. C., Colorado College.
6325 Rose, A. F., Colorado College.
6326 Palmer, J. C., Univ. of Illinois.
6327 Lockwood, C. H., Yale Univ.
6328 Peters, E. B., Yale University.
6329 Warrington, C. M., Univ. of Cinn.
6330 Latimer, C. W., Univ. of Toronto.
6331 Gleason, H. L., Wentworth Inst.
6332 Searing, H. R., Cooper Union.
6333 Kerrich, J. H., Lafayette Coll.
6334 Polster, M. A., Lehigh Univ.
6335 Downing, H. M., Ohio Nor. Univ.
6336 Shallcross, S. M., Delaware Coll.
6337 Leibold, C. A., Carnegie Inst. Tech.
6338 Metzer, R. A., Ohio State Univ.
6339 Steel, W., Univ. of Toronto.
6340 Reilly, F. P., Ohio Nor. Univ.
6341 Malaise, C. L., Univ. of Illinois.
6342 Gmeiner, E. V., Univ. of Mo.
6343 Thomas, C. W., Univ. of Mich.
6344 Watrous, F. C., Univ. of Mich.
6345 Gamon, R. L., Univ. of Mich.
6346 Engel, G. H., Univ. of Mich.
6347 Waung, S. H., Univ. of Mich.
6348 Farrell, H. F., Univ. of Mich.
6349 Bishop, J. S., Univ. of Cinn.
6350 Dace, F. E., Univ. of Illinois.
6351 Smith, D. J., University of Illinois.
6352 Everall, R. W., Bucknell Univ.
6353 Atsatt, J. L., Worcester Poly.
6354 Kenyon, B. H., Syracuse Univ.
6355 Coffman, A. B., Penn. State Coll.
6356 Shirley, J. G., Ohio Nor. Univ.
6357 Borroughs, W., Jr., Armour Inst. Technology.
6358 Tart, E. G., Wentworth Inst.
6359 Grimm, B. F., Cornell Univ.
6360 Packard, W., Cornell University.
6361 Brown, H. B., Kan. State Agri. Coll.

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6362 Farmer,G.L.,Kan.State Agri. Coll.
6363 Gross, L. G., Kan. St. Agri. Coll.
6364 Klaumann,C.J.,Kan.St.Agri. Coll.
6365 Barrows,C.A., Kan. St. Agri. Coll.
6366 Nicholson,M.A.,Kan.St. Agri Coll.
6367 Rumbel, O.K., Kan. St. Agri. Coll.
6368 Martindell, F., Cornell Univ.
6369 Russell, J. H., Univ. of Texas.
6370 Berkley, H. W., Univ. of Texas.
6371 Holporn, A. D., Univ. of Texas.
6372 Udden, S. M., Univ. of Texas.
6373 Gianotti, F. J., Univ. of Texas.
6374 Keller, A., Stanford University.
6375 Douglass, F. S., Purdue Univ.
6376 Coggeshall, K. M., Wash. Univ.
6377 Bellville, J. R., Wash. Univ.
6378 Aldrich, L. C., Wentworth Inst.
6379 Zi, S., Purdue University.
6380 Rummel, P. C., Jr., Rensselaer Polytechnic Institute.
6381 Gilmore, A. J., McGill Univ.
6382 Anderson, E. L., Univ. of Nebr.
6383 Edison, O. E., Univ. of Nebr.
6384 Ericson, M., Univ. of Nebr.
6385 Jenkins, R. C., Univ. of Nebr.
6386 Kaiser, A. A., Univ. of Penna.
6387 Knopf, C. M., Univ. of Penna.
6388 Knox, G. L., Univ. of Penna.
6389 Koplin, E. A., Univ. of Penna.
6390 McNabb, G. C., Univ. of Penna.
6391 Maraghan, W., Univ. of Penna.
6392 Ricciardi, S. D., Univ. of Penna.
6393 Sappington, R. D., Univ. of Pa.
6394 Richardson, D.F., Colo.Agri. Coll.
6395 Brown, C. C., Univ. of Calif.
6396 Lentz, R. V., Univ. of Kansas.
6397 Hudspeth, C.C., Tex. A.& M. Coll.
6398 Carmichael,G.F.,HighlandPk.Coll.
6399 Colchester,C.P.,Highland Pk.Coll.
6400 Johnson, J. F., Highland Pk. Coll.
6401 Halbert, C. T., Kan. St. Agri. Coll.
6402 Smith, W. R., Kan. St. Agri. Coll.
6403 Geisendorf,L.C.,Kan.St.Agri.Coll.
6404 Fickel, L. V., Kan. St. Agri.Coll.
6405 Plush, E.V.,Kan. State Agri. Coll.
6406 Davis, G. C., Wentworth Inst.
6407 Bricker, R. W., Ohio Nor. Univ.
6408 Warner, H. O., Penn. St. Coll.
6409 McDaniels, S. P., Lewis Inst.
6410 Lancey, R. E., Wor. Poly. Inst.
6411 Laker, C., Ohio Nor. University.
6412 Harned, M. L., Univ. of Cinn.
6413 Arnold, E. L., Univ. of So. Cal.
6414 Davison, M. C., Syracuse Univ.
6415 Ginley, J. J., Syracuse Univ
6416 Whalen, H. P., Syracuse Univ.
6417 Souza, M. E., Univ. of Cal.
6418 Rahner, M. L., Ga. Sch. Tech.
6419 Delf, L. E., Univ. of Mich.
6420 Dewars, A. G., Univ. of Minn.
6421 Philbrick,J.S.,Highland Park Coll.

ENROLLED MARCH 13, 1914

6422 Banes, C. R., Penna. State Coll.
6423 Erwin, L. B., Stanford University.
6424 Shoolbred, J., Jr., Lehigh Univ.
6425 Young, J. W., Univ. of Wisconsin.
6426 Steel, C. L., Penna. State Coll.
6427 Engsberg, R. W., Univ. of Wis.
6428 Kimball, J. T., Univ. of Wis.
6429 Grass, F. C., Highland Park Coll.
6430 Riggin, W. L., Ohio North. Univ.
6431 Stanford, A. G., Clemson College.
6432 Byrd, E. M., Clemson College.
6433 Morgan, G. R., Clemson College.
6434 Fletcher, J. E., Clemson College.
6435 Lachicotte, W. F., Clemson Coll.
6436 McDonald, F. H., Clemson Coll.
6437 Emerson, C. R., Clemson Coll.
6438 Thornhill, T. W., Clemson Coll.
6439 Brownie, G. H., Clemson Coll.
6440 Boozer, H. S., Clemson College.
6441 Jervey, F. J., Clemson College.
6442 Thornton, C. C., Clemson College.
6443 Des Champs, C. E., Clemson Coll.
6444 Rogers, T. B., Clemson College.
6445 Banks, D. H., Clemson College.
6446 Hunter, M. W., Clemson College.
6447 Spies, A. T., Lehigh University.
6448 Reitz, R. A., Lehigh University.
6449 Goldsmith, L. M., Drexel Inst.
6450 Underhill, A. M., Penna. St. Coll.
6451 Marks, E. O., Colorado Agri. Coll.
6452 Powers, W. P., Univ. of Pitts.
6453 Nash, I. H., Kansas St. Agri. Coll.
6454 Stockebrand, H. W., Kansas St. Agricultural College.
6455 Kirk, R. S., Kansas St. Agri. Coll.
6456 Hagan, J.S., Kansas St. Agri. Coll.
6457 Alsap, J. E., Kans. St. Agri. Coll.
6458 Padron, A., Rensselaer Poly. Inst.
6459 Guest, H. E., Rens. Poly. Inst.
6460 Ziegler, H. J., Rens. Poly. Inst.
6461 Bartram, E. W., Rens. Poly. Inst.
6462 Sticht, R. E., Rens. Poly. Inst.
6463 Best, R. E., Univ. of So. Calif.

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6464 Williams, E.E., Jr., Ga. Sch. Tech.
6465 Faulkner, L. W., Univ. of Ill.
6466 Ricker, C. W., Mass. Inst. Tech.
6467 Kreider, F. B., Ga. Sch. Tech.
6468 Warring, A., Univ. of Michigan.
6469 Clearwater, G. W., Syracuse Univ.
6470 Radway, E. S., Syracuse Univ.
6471 Kraft, C. H., Univ. of Missouri.
6472 Vossler, J. M., A.&M. Coll. of Tex.
6473 Williams, L. H., Ga. Sch. Tech.
6474 Laird, K. V., Univ. of Calif.
6475 Forster, G., Lehigh University.
6476 Oetzel, J. G., Clemson College.

## Past Section Meetings

### Boston

A meeting of the Boston Section was held in Tremont Temple on the evening of February 4, 1914. Three illustrated papers were presented on the subject "Recent Developments and Present Tendencies in Railroad Work", as follows:

1. "Rolling Stock", by Henry Bartlett, mechanical superintendent, Boston and Maine Railroad.
2. "Electrical Equipment," by Frederick D. Hall, electrical engineer, Boston and Maine Railroad.
3. "Permanent Way," by A. B. Corthell, chief engineer, Boston and Maine Railroad.

The meeting was held jointly with the Boston Society of Civil Engineers and the American Society of Mechanical Engineers, under the auspices of the latter society, with a total attendance of about three hundred. Mr. R. E. Curtis, secretary of the Boston Section, A. S. M. E., presided.

### Cleveland

On January 31 the members of the Cleveland Section went on an inspection trip through the White Company's automobile manufacturing plant. As soon as a group of five or six arrived at the plant, they were started with a guide through the factory. This trip gave the members an opportunity to see how a great many of the parts of a modern gasoline automobile were made and how the cars were assembled and finished.

The next regular meeting of the Cleveland Section was held in the Illuminating Building on Monday, February 23, Mr. E. A. Martindale presiding. There were 28 members and visitors present.

Mr. H. L. Wallau, electrical engineer of the Cleveland Electric Illuminating Company, presented a paper entitled "Notes on Large Turbine-Driven Direct-Current Generators." The paper was followed by a discussion by several members.

### Detroit-Ann Arbor

A paper on "Electrical Aids to Production in Factories" was presented by Mr. H. E. Eastwood of the Electric Controller and Manufacturing Company, Cleveland, Ohio, at the meeting of the Detroit-Ann Arbor Section on February 13.

The portion of the paper devoted to automatic acceleration and dynamic braking on motors driving machine tools was of most importance and interest. On lathes, planers, shapers and other machines operated at high speeds where it is necessary to make frequent stops to change the work and adjacent cutting tools, Mr. Eastwood gave figures showing the increase in production possible when the operator is relieved of the control of the driving motor. Mr. Eastwood's figures were in one instance expressed in pounds of chips per horse power per minute. Production increases as great as 45 per cent are not uncommon with many machine tools.

The employers' liability act now in force in many States has caused several companies to use dynamic braking to protect their workmen more fully. On machines where the clothing or parts of the body of the operator are apt to be caught and drawn into the machine, as simple an expedient as a rope may be stretched across the front of the machine and connected to the con-

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troller of the driving motor. A few pounds' tension in the rope serves to apply the brake and stop the motor.

Mr. Eastwood described in detail one installation of a group of machines driven from one motor. On each machine at a point convenient to the operator was located a push button switch for operating a dynamic brake. In case of an accident to any one man, any of the operators could stop the driving motor in time to prevent more serious injury and possible loss of life. On this particular installation the driving motor could be stopped dead in half a second and this without shearing off the motor or any of its connecting shafts.

This meeting was held in Detroit, with an attendance of 30. Vice-Chairman L. W. Eddy presided.

### Fort Wayne

A meeting of the Fort Wayne Section was held on February 19, at the Fort Wayne Electric Works, with a total attendance of 35. Chairman T. W. Behan presided.

Reports were made by the committees on by-laws and standardization. Mr. C. I. Hall then led a discussion of the methods of charging for electric power, with particular regard to the use of maximum demand meters in determining a basis of charge.

### Los Angeles

The meeting of the Los Angeles Section on February 28 was held at the Throop College of Technology, in Pasadena, and was conducted by the A. I. E. E. Branch at that institution. The total attendance was 59.

The following subjects were presented by members of the Throop Branch, either by papers or by inspection of the work being done: "Experiments on Y vs. Delta Systems," Walter L. Newton; "Local Pumping Cost," William F. Ayars; "Electric Equipment for Automobiles," G. D. Young; "The Design of an Automobile Testing Plant," H. B. Gerckens; "A High-Tension Transformer Design," A. W. Wells; "Experiments to Determine the Relation between Mechanical and Magnetic Properties for Iron and Steel," V. Morse; and "Comparative Gas Engine Tests for Different Fuels and Compressions," E. S. Gardiner. There was also a conducted inspection of the laboratory equipment at Throop. It was voted a most interesting and instructive meeting by those who attended.

At this meeting the Los Angeles Section adopted resolutions of sympathy and condolence, on learning of the death of C. A. Howell, Mem. A. I. E. E., of the Southern California Edison Company, and A. W. Lindgren, Assoc. A. I. E. E., of the Huntington Beach Utilities Company.

### Lynn

At the meeting of the Lynn Section on February 18, in Burdett Hall, a lecture on "Color Photography" was given by Professor Elihu Thomson, to an audience of 460 members and visitors. Chairman E. R. Berry introduced the speaker.

Before speaking of the methods of recording color by photographic means Professor Thomson touched upon the peculiarities of pigment in substances and particularly on the sensitiveness of such colors to the action of reagents. He then illustrated, by means of a chart of ether waves, the vibrations of different frequencies, beginning with ordinary frequencies of electrical transmission on conductors, and passing up through wireless transmission frequencies, Hertzian waves, infra-red heat waves, light rays of the visible spectrum, ultra-violet rays, and the highest rates of vibration so far known, exemplified in the Roentgen rays and the gamma rays from radium. After describing the method by which the eye sees color, and demonstrating, by means of the sodium flame and color disks, the combining and overlapping of color sensations, Professor Thomson took up the different methods of color photography.

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He described the work of Ives, R. W. Wood, Lippman, and the Lumiere brothers. Slides were shown to illustrate the different kinds of color work in photography.

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The next meeting of the Lynn Section was held on March 6, in Burdett Hall, with an attendance of 276. Chairman E. R. Berry presided.

The two speakers were Manager Walter C. Fish of the Lynn Works of the General Electric Company, who was the founder of the Section, and Professor Elihu Thomson. Mr. Fish, speaking on "Side Lights on Our Work," touched on the progress of science, the economic and moral causes of the high cost of living, the problem of immigration, and the need of social science—not sentimentalism, but the real study of man by man. Professor Thomson emphatically advocated the study of evolution, and said that our legislators were in need of a closer knowledge of the gradual working of evolutionary processes. He also spoke of the X-ray investigations being conducted by Dr. W. D. Coolidge.

### Madison

At the meeting of the Madison Section on December 18, 1913, Professor J. W. Shuster of the electrical engineering department, University of Wisconsin, presented a paper entitled "Electric Service for the City of Madison." The question of electric rates and service for Madison is a live issue, since the possibility of obtaining electric power from Prairie du Sac by high-tension transmission has been under discussion for considerable time. In his paper, Professor Shuster explained the different methods which might be used to arrive at the rates now used by the Madison Gas and Electric Company. The data used in illustration were taken from statistics of the Railroad Commission of Wisconsin. The paper was presented with a view to bringing out discussion.

In the discussion, Professor C. M. Jansky described the methods used by the Ontario Hydroelectric Commission, both from an operating standpoint and with reference to the determination of rates. He criticized the methods used in many places in arriving at rates. Mr. M. H. Collbohm explained the rapidly increasing reliability of well designed present-day high-tension transmission systems, showing how interruptions to service may be reduced to a value which in many cases cannot be met in the operation of a system supplied by a steam plant. Mr. E. H. Kifer, Madison Gas and Electric Company, and Mr. Dudley Montgomery, Southern Wisconsin Railway Company, discussed the matters of machine factors and rates for street railway power service. A number of questions pertaining to the situation were asked and answered by others present.

Chairman Edward Bennett presided, and the total attendance was 49.

### Mexico

The March meeting of the Mexico Section was held on March 3 at the Restaurant Bach, Mexico City, with an attendance of 25 members and guests. Secretary James Carson presided.

At the close of the dinner, Messrs. Will N. Parsons and Enrique Hubard presented papers on the electrical contractor in Mexico. Mr. Hubard, who spoke in Spanish, advocated the registration of all electricians in Mexico City after examination by competent authorities, as a means of doing away with the handicap electrical contractors are under because of the activities of unscrupulous itinerant electricians. This suggestion was received most favorably by the audience. Mr. Parsons' address was of a humorous nature, and pictured the versatility required of an electrical contractor in Mexico.

### Minnesota

The regular monthly meeting of the Minnesota Section was held in the Main Engineering Building at the

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University of Minnesota, Minneapolis, on February 16.

The program consisted of two papers, the first one being given by Mr. V. S. Beck, manager of the Beck Electrical Construction Company. This paper related to the use, but more particularly a discussion of some tests which had been made, of "High-Tension Fuses." By high tension is meant pressures as high as 100,000 volts. The paper was illustrated with a number of stereopticon slides, showing the effect of the rupture of the circuit carrying this high-voltage current, and it appeared that fuses were now available which could safely handle this kind of current equally well as, if not better, than circuit breakers. The point was brought out that the fuses interrupted the current more quickly than circuit breakers and that this extremely quick action would not cause severe surges or other serious line disturbances.

The next paper was presented by Mr. Robert F. Pack, vice-president and general manager of the Minneapolis General Electric Company, and was entitled "The People and Public Service Corporations." This paper was a very frank discussion of Mr. Pack's view of the relation which should exist between public service corporations and the public. He stated that while the sentiment was growing for publicly owned public utilities, the time had not yet arrived for as satisfactory service under this arrangement as was now being given by properly controlled, but privately owned, companies. He stated that such business as that in which his company was engaged was and should be monopolistic in character, and that such companies should be under the control of a competent commission. He believed such commissions would be appointed in the near future, where they were not already existing, and urged that engineering societies should see to it that the engineering profession is properly represented on such commissions, as such matters are more engineering problems than purely legal and financial ones.

Chairman W. T. Ryan presided, and the total attendance was 68.

### Panama

The third meeting of the Panama Section was held in the offices of the Panama Railroad, Colon, Republica de Panama, Sunday, February 1. The meeting was called to order at 2:35 p.m. by Vice-Chairman Ernest E. Lee. Thirty-four were present.

Mr. W. H. Fenley delivered a paper on "Interlocking and Automatic Signals," describing at length the early history and later development of railway signals and interlocking plants. The paper covered the field of signal engineering, with a detailed explanation of many features, track circuits, alternating-current versus direct-current supply, automatic signal mechanisms, blocks, etc. Mr. Fenley illustrated and explained the various types of signal used on the Panama Railroad by using miniature models, in which the signal arms could be moved by hand to all positions.

Mr. A. B. Kratz presented a paper entitled "How the Telephone Helped to Build the Panama Canal." Mr. Kratz gave a history of the early troubles encountered by the telephone men in developing the present efficacious system from the single line of pre-American days. Mr. Kratz spoke of the different types of pole lines which have been installed at various times—concrete poles with wooden cores, creosoted poles, iron-pipe poles, and the clamped rail type of pole which is now used to carry from forty to eighty wires.

A discussion of the two papers followed, in which Messrs. Rowe, Lee, Clark, Reddig, Ely, Myrick and McCann participated.

### Philadelphia

The Philadelphia Section held a meeting at the Engineers' Club on March 9. Chairman A. R. Cheyney

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presided, and the total attendance was 169.

Dr. Hoadley gave a short talk on the proposed joint meeting of all the engineering societies in Philadelphia, and Mr. Stevens made a short address for the Public Policy Committee, and called the attention of the members to the International Electrical Congress to be held in San Francisco in 1915.

Captain L. S. Ryan, having been unexpectedly ordered to Oklahoma, was unable to be present, but sent his paper on "Applications of Electricity in the Army," which was read by Mr. Hornor. Naval Constructor J. G. Tawresey presented a paper on "Applications of Electricity in the Navy," and Mr. Maxwell W. Day presented a paper on "The Manufacture of Electrical Apparatus for the Army and Navy."

The discussion which followed was participated in by Naval Constructors Snow, Linard, Wright, Bankson and Tawresey, and Messrs. Stevens, Hornor, Penrose, Goodwin and Day.

### Pittsfield

The eighth meeting of the Pittsfield Section for the season was held on Thursday, February 12, at the Berkshire Athenaeum. Mr. J. J. Frank, chairman of the Section, presided, and the total attendance was 30.

The paper of the evening was presented by Messrs. M. E. Tressler and J. P. Minton, of the Pittsfield works laboratory of the General Electric Company. The subject of their talk was the "Cathode Ray Tube and Its Applications." This was of particular interest because the paper was based on the actual experiences of the authors with the cathode ray tube during the past year or more.

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The ninth meeting of the Section was held on March 5 at the Wendell Hotel. Dr. W. S. Franklin of Lehigh University spoke on the subject of "Coupling of Circuits." By using lantern slides and a number of mechanical models Dr. Franklin made his subject extremely clear.

The attendance at this meeting was 103.

### St. Louis

The eighty-seventh meeting of the St. Louis Section was held jointly with the Engineers Club of St. Louis in the rooms of the latter organization on the evening of January 21. Chairman F. J. Bullivant presided, and twenty members and twenty-four guests were present.

Two papers were presented on this occasion, the first by Mr. Hugo Wurdach, consulting engineer. Mr. Wurdach spoke on "Special Features of Power Plant Equipment for the Railway Exchange Building," with special reference to the layout of the plant, showing how special boiler construction and arrangement of steam piping contributed to a satisfactory arrangement in the limited space available.

"Power Plant Equipment for the Laclede Gas Light Company" was the subject of the second speaker, Mr. William Bradford, electrical engineer for the Laclede Power Company. With the aid of blue prints and photographs, Mr. Bradford described the arrangement of the plant, the method of handling coal and ash, and also the method of filtering the water taken from the Mississippi river.

### Schenectady

The Schenectady Section held a meeting on February 10 in the Edison Club Hall, at which the attendance was 175. Chairman George H. Hill presided.

The subject of the evening was "Modern Conceptions of Electricity," presented by three speakers. The first was Dr. Whitney, who discussed briefly the value to the Research Laboratory of keeping abreast with the latest developments in theoretical aspects of physics and especially of the influence that the introduction of new concepts in physics has had on electrical engineering. The electron theory, radioactive phenomena,

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the extension of the spectrum to X-rays and Y-rays as the upward limit of frequencies of electromagnetic radiation and the recent theories of the structure of the atom, were mentioned as interesting and important recent developments in physics.

Dr. I. Langmuir outlined the main features of the electron theory and showed how, by means of this theory, one could explain the production of electromagnetic waves, the phenomena of conductance in solids and gases, and the production of the magnetic field. The speaker discussed the most recent views on the structure of the atom and the molecule and also spoke of the manner in which Bragg and others have been able by means of X-ray photographs to determine crystal structure.

Dr. S. Dushman mentioned briefly the result obtained from the investigation of the laws of distribution of energy in the spectrum of black body radiation and the argument which led Planck to postulate an atomistic theory of energy, or quantum theory, as it has been designated. The speaker also mentioned the application of the theory to the fields of specific heats, X-rays and photo-electric effects.

### Toledo

The Toledo Section had a meeting on March 6, at the Toledo Commerce Club, which was attended by twenty members and visitors.

Mr. Walter Coakley, of the Toledo Railways and Light Company, addressed the meeting on the manufacture of illuminating gas. Mr. Coakley had a miniature gas plant to demonstrate the methods of manufacture. A general discussion followed.

### Urbana

The Urbana Section met on February 14, in the electrical engineering laboratory of the University of Illinois. Mr. F. H. Millener, who is experimental engineer for the Union Pacific Railroad, gave a lecture on "Wireless Telegraphy for Railroads."

Chairman Morgan Brooks presided. The attendance was 45.

### Vancouver

The Vancouver Section held a meeting on January 9, in the British Columbia Electric Railway Company's lecture room. Chairman E. M. Breed presided. At this meeting Mr. J. H. Paget concluded his paper on "Direct-Current Switchboard Meters," the first part of which had been presented at the preceding regular meeting. A discussion followed, in which most of the members present took part.

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The next meeting of the Section was held on February 27, in the rooms of the University Club. Chairman Breed presided, and forty members were present.

After the executive business had been transacted, Mr. John Montgomery presented a paper on "Central Station Practise as Applied to Solicitation and Retention of Business," which was followed by a general discussion.

### Washington, D.C.

A joint meeting of the Washington Section of the American Institute of Electrical Engineers and the Washington Society of Engineers was held in the lecture room of the Cosmos Club, on Tuesday, February 10. Mr. Bion J. Arnold, of Chicago, was the speaker of the evening and made some remarks on "Some Applications of the Principles of Conservation to the Readjustment of Relations between Municipalities and Urban Railways." The societies were fortunate in having as their guests two of the Commissioners of the District of Columbia and the president of one of the principal public service corporations of the District. Mr. Ralph W. Pope was also present. All of these gentlemen made interesting contributions to the discussion on Mr. Arnold's remarks.

The total attendance was approximately two hundred. Chairman H. C. Eddy presided.

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## Personal

MR. W. S. MURRAY was on March 16 appointed by the New York, New Haven and Hartford Railroad Company to be consulting engineer in general charge of all electrical engineering and construction, reporting to President Hustis, with offices at New Haven. Mr. Murray, following the substantial completion of the construction of the system for complete electrical operation west of New Haven, will enter into closer relations with the railroad company. His jurisdiction will hereafter be extended to include also the electrical features of operation in addition to electrical construction. He will continue with the firm of McHenry and Murray in general consulting practise as before.

## Obituary

EDWIN JAMES HOUSTON, Ph. D., Member and Past-President of the A. I. E. E., died of heart disease at his home in Philadelphia on March 1, 1914. Professor Houston was born in Alexandria, Va., July 9, 1847, and educated principally in the public schools and in the Central High School of Philadelphia, which school he was to serve long and faithfully as professor of physical geography and natural philosophy. After teaching for a time at Girard College, he was elected professor of civil engineering in the Central High School. He was soon after transferred to the chair of natural philosophy, of which he was professor emeritus at the time of his death. Professor Houston interested himself in the new subject of electric lighting about 1879, and together with Professor Elihu Thomson, who was also teaching at that time in the Central High School, worked out the Thomson-Houston system of arc lighting, which made its appearance in 1881 and soon won its way into prominence all over the civilized world. The Thomson-Houston dynamo embodied many novel features of design which aroused a great deal of interest. The work done during this partnership of two years forms part of the history of electrical engineering, and Professor Houston's many inventions in the field of arc lighting met with deserved success. Professor Houston was a charter member of the American Institute of Electrical Engineers, being elected an Associate on April 15, 1884, and transferred to the grade of Member on October 21 of the same year. In that year Professor Houston had been appointed by the United States government a member of the United States Electrical Commission, which convened in Philadelphia, and he was also elected by the Franklin Institute chief engineer of the International Electrical Exhibition in Philadelphia. This exhibition was well carried out, and the practical tests of electrical apparatus then made were a valuable contribution to the advance of electrical science. From this time on, Professor Houston was prominent in electrical research of every sort, and also devoted much of his time to the popular exposition of electrical knowledge by lectures and textbooks. He was keenly alive to the growing importance of science in education, and was not only an inspiring teacher, but a sympathetic friend, to the young men who came under his influence. He resigned from the Central High School about 1895, and became associated with Dr. A. E. Kennelly, now of Harvard University, in consulting engineering practise, and he maintained an office in Philadelphia as a consulting engineer up to the time of his death. His contributions to the literature of natural science were numerous, and were written in a terse and vigorous style characteristic of the man. Of his fifty-two books perhaps the best-known to electrical men are the "Dictionary of Electrical Words, Terms and Phrases," "Electricity in Every-Day Life," and the electrotechnical series written in collaboration with Dr. Kennelly and published in the *Electrical World* years ago. The latter were among the first primers on electrical subjects appear-

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ing in any language. Professor Houston was elected president of the Institute in 1893 and again in 1894. He was professor emeritus of physics at Franklin Institute, professor of physics at the Medico-Chirurgical College, a member of the American Institute of Mining Engineers, the American Philosophical Society, the Philadelphia Academy and many other scientific organizations. He was president of Section C of the Electrical Congress held in Chicago in 1893, and the first president of the electrical section of the Franklin Institute. He received the honorary degree of Ph. D. from Princeton University.

At the meeting of the Board of Directors on March 13, 1914, the following resolutions were adopted:

*Whereas*: on March 1, 1914, the American Institute of Electrical Engineers sustained the sad loss of one of its Past-Presidents, and a very large number of non-members suffered the great loss of a universally beloved friend and teacher, in the death of Edwin James Houston, A. B., A. M., Ph. D. (hon.), of Philadelphia, whose work in the application of electricity to the industries, especially in that early trying period when so little precedent existed, brought him credit and fame both here and abroad, and whose attractive method of teaching his many young pupils and friends developed their interest and laid the foundation of the future careers of many who are now following the profession of electrical engineering and other branches of applied science; and

*Whereas*: Edwin J. Houston was one of the first members of this Institute, was elected to its presidency in 1893 and again in 1894;

*Be it resolved*: that the Board of Directors of the American Institute of Electrical Engineers hereby places on record its sense of the great loss sustained and its appreciation of his agreeable personality, his career, his exceptional abilities to interest young men in the pursuit of applied science, his long continued and active interest in this Institute, and his sincere sympathy with its objects, by which he made many warm and lasting friends; and

*Be it further resolved*: That the sympathy and condolence of the Board of Directors of the Institute be extended to the bereaved relatives; and

*Be it further resolved*: That these resolutions be transmitted to his nearest relatives, and that a copy be preserved in the archives of the Institute.

---

GEORGE WESTINGHOUSE died at New York, March 12, 1914, in the sixty-eighth year of his age. His contributions to "advancement of the theory and practise of electrical engineering and of the allied arts and sciences," the work to which this Institute is dedicated, have been such as to win for him the highest appreciation and gratitude not alone of the members of this body, but of the entire civilized world.

Prior to entering the field of electrical engineering, Mr. Westinghouse had, by reason of the development and introduction of his air brake, become well-known and honored both here and abroad.

During the past quarter of a century, he has found the time to carry on the further development of the air brake, railway signaling apparatus, the development and introduction of the geared steam turbine, the air-spring, and many other forms of mechanical apparatus, and at the same time, to organize and develop the Westinghouse Electric and Manufacturing Company.

In the present note we shall undertake to treat only of his contributions to the electrical field and these only in outline. His first excursions into that field consisted of the development and patenting of an electro-pneumatic brake, and, later, an automatic telephone exchange.

In 1884, Mr. Westinghouse first became interested in electric lighting. Becoming acquainted with William Stanley, he acquired the latter's rights to his incandescent lamp and engaged him to come to Pittsburgh. The following year, the Gaulard and Gibbs system of distribution of alternating currents by series transformers was brought to his attention, and he sent Franklin Leonard Pope, past-president of this Institute, to England to investigate its operation. This resulted in the purchase by Mr. Westinghouse of the American rights. Mr. Reginald Belfield, then an electrician for Messrs. Gaulard and Gibbs, brought over a number of transformers and a Siemens alternator.

The work of Mr. Westinghouse in connection with natural gas systems where the gas was sent through relatively small pipes over long distances,

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at high pressure, and distributed to the consumer under reduced pressure, led him to believe that electric current could be advantageously distributed at high voltage and locally reduced by transformers, or converters, as they then were called. He therefore urged upon his assistants, Mr. Stanley, Mr. Belfield, and Mr. Shallenberger, a young graduate of the Naval Academy, the importance of developing, in a practical manner, the somewhat crude Gaulard and Gibbs system.

In the fall of 1885, Mr. Westinghouse arranged with Mr. Stanley for the latter to establish an experimental laboratory at Great Barrington, Mass., and there to devote his time to developing generators and transformers better suited for the constant-potential system. In March, 1886, Mr. Stanley was able to place these transformers in successful operation, and by the end of that year Mr. Westinghouse was prepared to launch the new system commercially, but he was able to do so only after overcoming the most severe opposition on the part of those who claimed that it was fraught with dangerous qualities.

While Mr. Westinghouse made many inventions in the electrical field, he recognized that it was of the utmost importance to his company that the development work should be rapid, and he therefore gathered about him a group of young men of inventive minds. The energy, skill and inventive genius of Mr. Westinghouse himself, were a constant source of inspiration and encouragement to each of these associates, and he was always scrupulous to give to them full credit for inventions made by them, evincing a keen interest in the progress of their work, and aiding in every way by suggestion and counsel.

In 1888, Mr. Westinghouse acquired for his company the alternating-current patents of Nikola Tesla, and it was at the Pittsburgh works that Mr. Tesla, and the other associates, developed the practical forms of the induction motor. At about the same time there were developed the Shallenberger meter and the Stillwell regulator, each of these devices being important contributions to the alternating-current system.

An instance of his ability to cope with the most difficult problems was shown in carrying out the contract for lighting the World's Fair in Chicago, in 1893. When this contract was awarded to his company, Mr. Westinghouse arranged to build dynamos of a size not theretofore contemplated, and, being confronted with the task of providing incandescent electric lamps which should not infringe the Edison lamp patents which had been sustained by the courts at about that time, he devised the so-called stopper lamp, and ingenious automatic machines for grinding the filament-carrying stopper into the neck of the lamp, thus defeating the prophecy, which had been freely made, that he would not be able to carry out the contract because of inability to provide the Edison lamps.

Among his more recent inventions is the electro-pneumatic train control system which has been largely introduced on electric railways.

Mention should also be made of his quick appreciation of the importance to the electrical art of the invention by Peter Cooper Hewitt of the Cooper Hewitt lamp and of the Cooper Hewitt rectifier. Acquiring a considerable interest in these inventions, Mr. Westinghouse, in conjunction with Dr. Hewitt, organized the Cooper Hewitt Electric Company in 1902.

The more difficult the task with which Mr. Westinghouse was confronted, the greater the zeal with which he sought its solution, and the fertility of his mind was such that he seldom failed to accomplish a desired result.

Mr. Westinghouse's personality endeared him to all his associates. He was constantly seeking to improve the conditions of his employees. He was the first manufacturer to introduce the Saturday half-holiday in this country. He saw to it that the surroundings of the workmen in the shops of all his

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industries were such as to promote health and comfort. To him the acquisition of wealth was a secondary consideration, and money meant for him, merely the means for further promoting the welfare of mankind. Mr. Westinghouse found recreation in entertaining friends at his home, always taking a deep personal interest in each of his guests.

In 1911, the American Institute of Electrical Engineers awarded to Mr. Westinghouse the Edison Gold Medal "for meritorious achievements in connection with the development of the alternating-current current system for light and power," and this medal was presented to him at the Annual Convention in Boston in June, 1912. He had also received various decorations abroad and was a member of many scientific societies. Last year he was awarded the Grashof Medal, the presentation of which was arranged for in New York, at the Annual Meeting of the American Society of Mechanical Engineers, but unfortunately, Mr. Westinghouse, by reason of his illness, was unable to be present to receive the medal in person.

At the meeting of the Board of Directors of the Institute, held on March 13, 1914, the following resolution was adopted:

*Whereas*, George Westinghouse, an honored member of this Institute, died on March 12, 1914, and,

*Whereas*, his contributions to the advancement of science and the useful arts were such as to receive well-merited recognition throughout the world, and the integrity of his character won for him the admiration of mankind; and,

*Whereas*, his contributions to the development of the applied arts of electricity alone were so great as to rank him among the foremost of men in the field to which the work of this Institute is especially devoted; and,

*Whereas*, this Institute desires to record in its Minutes, the high appreciation in which his memory is held by its members;

*Now, Therefore*, be it

*Resolved*; that this Insitute hereby expresses its feeling of deep personal loss incurred by the death of George Westinghouse; its recognition of the great value to the world of the results of the energy, courage and wisdom which he devoted to the upbuilding and progress of the electrical arts; its sincere admiration of the generous and manly qualities of the man which endeared him to all, and its desire to pay to his memory the highest tribute within its power; and be it

*Further Resolved*; that a copy of this resolution be sent to his family.

## Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

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| Cleveland.....Sept. 27, '07 | J. C. Lincoln. | R. E. Scovel, 1663 East 86th Street, Cleveland, Ohio. |
| Detroit-Ann Arbor.Jan. 13, '11 | A. R. Sawyer. | Ray K. Holland, Cornwell Building, Ann Arbor, Mich. |
| Fort Wayne.....Aug. 14, '08 | T. W. Behan. | P. H. Haselton, Fort Wayne Electric Works Ft. Wayne, Ind. |
| Indianapolis-Lafayette.Jan. 12, '12 | O. S. More. | G. B. Schley, 805 Pythian Building, Indianapolis, Ind. |
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| Madison.....Jan. 8, '09 | Edward Bennett. | F. A. Kartak, Univ. of Wisconsin, Madison, Wis. |
| Mexico.....Dec. 13, '07 | Norman Rowe. | James Carson, Mexican Light and Power Company, Mexico City, Mexico. |
| Milwaukee.....Feb. 11, '10 | L. E. Bogen. | L. P. Coulter, 2500 Chestnut Street, Milwaukee, Wis. |
| Minnesota.....Apr. 7, '02 | W. T. Ryan. | Fred G. Dustin, 9 South Fifth St., Minneapolis, Minn. |
| Panama.....Oct. 10, '13 | Edward Schildhauer. | W. R. McCann, Isthmian Canal Commission, Culebra, Canal Zone |
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| Pittsfield.....Mar. 25, '04 | J. J. Frank. | G. W. Wade, General Electric Company, Pittsfield, Mass. |
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| San Francisco...Dec. 23, '04 | A. H. Griswold. | A. G. Jones, 819 Rialto Building, San Francisco, Cal. |
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| Toronto.....Sept. 30, '03 | D. H. McDougall. | H. T. Case, Continental Life Bldg., Toronto, Ont. |
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| Vancouver.....Aug. 22, '11 | E. M. Breed. | L. G. Robinson, 1003 Holden Building, Vancouver, B. C. |
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| **Armour Institute**.....Feb. 26, '04 | E. L. Nelson. | T. C. Bolton, Armour Inst. Tech., Chicago, Ill. |
| **Bucknell University**.....May 17,'10 | F. O. Schnure. | J. M. Hillman, Bucknell University, Lewisburg, Pa. |
| **California, Univ. of**.....Feb. 9, '12 | Charles Z. Yost. | L. E. Rushton, University of California, Berkeley, Cal. |
| **Cincinnati, Univ. of**.....Apr. 10, '08 | John H. Stewart. | J. S. Bishop. 2345 Kemper Lane, Cincinnati, Ohio. |
| **Clemson Agricultural College**.....Nov. 8, '12 | F. J. Jervey. | F. H. McDonald, Clemson College, S. C. |
| **Colorado State Agricultural College**.....Feb. 11, '10 | L. M. Klinefelter. | R. K. Havighorst. Colorado State Agricultural College, Fort Collins, Colo. |
| **Colorado, Univ. of**.....Dec. 16, 04 | L. E. Sweitzer. | Frank A. Redding, University of Colorado, Boulder, Colo. |
| **Highland Park College**..Oct. 11, '12 | E. B. Williams, | Ralph R. Chatterton, Highland Park College, Des Moines, Iowa. |
| **Iowa State College**.....Apr. 15, '03 | Earle G. Nichols. | F. A. Robbins, Iowa State College, Ames, Iowa. |
| **Iowa, Univ. of**.....May. 18, '09 | J. H. Scanlon. | A. H. Ford, University of Iowa, Iowa City, Ia. |
| **Kansas State Agr. Col**...Jan. 10, '08 | L. O'Brien. | W. C. Lane, Kansas State Agric. Col., Manhattan, Kan. |
| **Kansas, Univ. of**.....Mar. 18, '08 | H. C. Hansen. | L. M. Bocker, Univ. of Kansas, Lawrence, Kansas. |
| **Kentucky State Univ. of**.Oct. 14, '10 | H. B. Hedges. | H. Tyler Watts, 315 East Maxwell Street, Lexington, Ky. |
| **Lafayette College**.....Apr. 5, '12 | G. P. Ellis. | V. A. Davison, Lafayette College, Easton, Pa. |
| **Lehigh University**.....Oct. 15, '02 | W. B. Todd. | G. Forster, Lehigh University, S. Bethlehem, Pa. |
| **Lewis Institute** .....Nov. 8, '07 | A. H. Fensholt, | Fred A. Rogers, Lewis Institute, Chicago, Ill. |
| **Maine, Univ. of**.....Dec. 26, '06 | C. M. Kelley. | E. L. Getchell, University of Maine, Orono, Maine. |
| **Michigan, Univ. of**.....Mar. 25, '04 | P. H. Evans. | E. T. Anderson, 608 Mary Court, Ann Arbor, Mich. |
| **Missouri, Univ. of**.....Jan. 10, '03 | H. B. Shaw. | E. W. Kellogg, 9 Engineering Building, Columbia, Mo. |
| **Montana State Col**.....May 21, '07 | Max W. Kenck. | J. A. Thaler, Montana State College, Bozeman, Mont. |

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## LIST OF BRANCHES—Continued

| Name and when Organized | Chairman | Secretary |
|---|---|---|
| **Nebraska, Univ. of**.....Apr. 10, '08 | Olin J. Ferguson. | V. L. Hollister, Station A, Lincoln, Nebraska |
| **New Hampshire Col**.....Feb. 19, '09 | | |
| **North Carolina Col. of Agr. and Mech. Arts**.....Feb. 11, '10 | Wm. H. Browne, Jr. | James Fontaine, West Raleigh, N. C. |
| **Ohio Northern Univ**.....Feb. 9, '12 | George E. Boesger | Harry Restofski, Ohio Northern University, Ada, Ohio. |
| **Ohio State Univ**.....Dec. 20, '02 | L. R. Yeager. | John M. Strait, Ohio State Univ., Columbus, Ohio. |
| **Oklahoma Agricultural and Mech. Col**.....Oct. 13, '11 | A. P. Little. | Quentin Graham, 416 Hester Street, Stillwater, Okla. |
| **Oklahoma, Univ. of**.....Oct. 11, '12 | R. D. Evans. | L. J. Hibbard, Univ. of Oklahoma, Norman, Okla. |
| **Oregon Agr. Col**.....Mar. 24, '08 | A. O. Manigold. | I. L. Olmstead, Oregon Agric. Col., Corvallis, Ore. |
| **Oregon, Univ. of**.....Nov. 11, '10 | C. R. Reid. | C. H. Van Duyn, Univ. of Oregon, Eugene, Oregon. |
| **Penn State College**.....Dec. 20, '02 | T. A. Jones. | A. D. Shultz, State College, Pa. |
| **Pittsburgh, University of**. Feb. 26, '14 | | |
| **Purdue Univ**.....Jan. 26, '03 | C. F. Harding. | A. N. Topping, Purdue University, Lafayette, Ind. |
| **Rensselaer Poly. Inst**....Nov. 12, '09 | W. J. Williams, | H. P. Wilson Rensselaer Poly. Institute, Troy, N. Y. |
| **Rose Polytechnic Inst**....Nov. 10, '11 | Charles F. Harris. | Claude A. Lyon, 1331 Liberty Avenue, Terre Haute, Ind. |
| **Rhode Island State Col**..Mar. 14, '13 | Harry Webb. | P. M. Randall, Rhode Island State College, Kingston, R. I. |
| **Stanford Univ**.....Dec. 13, '07 | G. O. Wilson. | L. M. Bussert, Stanford University, Cal. |
| **Syracuse Univ**.....Feb. 24, '05 | W. P. Graham. | R. A. Porter, Syracuse University, Syracuse, N. Y. |
| **Texas, Univ. of**.....Feb. 14, '08 | Joseph W. Ramsey, | J. A. Correll. University of Texas, Austin, Tex. |
| **Throop College of Technology**.....Oct. 14, '10 | W. L. Newton, | A. W. Wells, Throop Poly. Institute, Pasadena, Cal. |
| **Vermont, Univ. of**.....Nov. 11, '10 | | |
| **Virginia, Univ. of**.....Feb. 9, '12 | Walter S. Rodman | H. Anderson, Jr., 1022 West Main St., Charlottesville, Va. |
| **Wash., State Col. of**....Dec. 13, '07 | M. K. Akers. | H. V. Carpenter, State Coll. of Wash., Pullman, Wash. |
| **Washington Univ**.....Feb. 6, '04 | R. D. Duncan, Jr. | C. C. Hardy, Washington University, St. Louis, Mo. |
| **Washington, Univ. of**...Dec. 13, '12 | A. P. Newbury. | Charles A. Stanwick, Univ. of Washington, Seattle, Wash. |
| **Worcester Poly. Inst**....Mar. 25, '04 | W. C. Blanchard. | Harry B. Lindsay, Worcester Poly. Inst., Worcester, Mass. |
| **Yale University**.....Oct. 03, 10 | R. G. Warner. | K. B. Jones, 70 Trumbull St., New Haven, Conn. |

**Total, 48.**

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# SECTION II

# PROCEEDINGS

of the

# American Institute

of

# Electrical Engineers

## Papers, Discussions and Reports

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**PROCEEDINGS**

OF THE

**American Institute**

OF

**Electrical Engineers.**

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol XXXIII May, 1914 No. 5

## Annual Meeting of the Institute in New York, May 19, 1914

The 295th meeting of the American Institute of Electrical Engineers will be held in the auditorium of the Engineering Societies Building, 33 West 39th Street, New York, on Tuesday, May 19, 1914, at 8:15 p.m. This is the regular annual business meeting of the Institute, at which the Board of Directors will present its report for the fiscal year ending April 30, 1914, including a detailed statement of the financial status of the Institute, and a summary of the work accomplished by the standing and special committees during the year. The Committee of Tellers will present its report on the result of the election of officers for the coming administrative year.

Following the business meeting a technical session will be held, the program for which was arranged by the Committee on the Use of Electricity in Marine Work. Two papers will be presented: *The Future of Electric Heating and Cooking in Marine Service*, by H. J. Mauger, and *Electricity the Future Power for Steering Vessels*, by H. L. Hibbard. These are printed in this issue of the PROCEEDINGS.

At the close of the technical session the meeting will adjourn to the Institute rooms on the 10th floor, where a smoker will be held and light refreshments served.

## Institute Meeting in Pittsfield, Mass., May 28-29, 1914

The 296th meeting of the Institute will be held in Pittsfield, Mass., May 28-29, 1914, under the auspices of the Pittsfield Section. The general subject for discussion is to be "Relative Advantages of Y and Delta Connections."

The A. I. E. E. headquarters for the meeting will be at the Maplewood Hotel, and the technical sessions will be held in the convention hall. Members and guests should register at Institute headquarters promptly upon their arrival.

No special transportation rates have been obtained for this meeting. Members should consult their local ticket agents regarding routes and rates.

The following program has been arranged:

THURSDAY MORNING, MAY 28
9:00 A.M.
Registration
AFTERNOON SESSION
2:00 P.M.

Opening address.

1. *Experiences with Line Transformers*, by D. W. Roper.
2. *Experience of the Pacific Gas and Electric Company with the Grounded Neutral*, by J. P. Jollyman, P. M. Downing and F. G. Baum.

THURSDAY EVENING
8:00 P.M.

The Berkshire County University Club will hold its annual dinner at the Maplewood Hotel. All members of the American Institute of Electrical Engineers are invited to attend. Tickets ($2.00 per plate) should be obtained promptly upon arrival at Institute headquarters.

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FRIDAY MORNING, MAY 29
9:00 A. M.

3. *Influence of Transformer Connections on Operation*, by Louis F. Blume.
4. *A Study of Some Three-Phase Systems*, by Charles Fortescue.

FRIDAY AFTERNOON

The afternoon will be devoted to entertainment. Arrangements are being made for events in golf, boating, tennis, motoring and other sports, through the courtesy of the Pittsfield Country Club and Pittsfield Boat Club.

EVENING SESSION
8:00 P.M.

5. *Harmonic Voltages and Currents in Y and Delta-Connected Transformers*, by R. C. Clinker.
6. *Relative Merits of Y and Delta Connection for Alternators*, by T. S. Eden.

Written discussions by Mr. Guido Semenza of the Edison Company of Milan, and by Mr. Ferdinand Koscherak of the Thomson-Houston Company of Paris, will be read.

The entire program will be summarized and discussed at the close of the meeting by Mr. Percy H. Thomas.

NOTE: The six numbered papers of the above program are published in this issue of the PROCEEDINGS.

HOTELS AND RATES

Each member should arrange for his own hotel accommodations. Correspondence regarding reservations should in all cases be directed to the hotel management.

| Hotel | Proprietor | Plan | Rates per day |
|---|---|---|---|
| Maplewood | A. W. Plumb | American | $4.00 |
| American House | Plumb & Clark | Am. and Eur. | 3.00 and 1.50 |
| Wendell | John W. Downes | European | 1.50 |

## Annual Convention, Detroit, Mich., June 23-26, 1914

The work of preparation for the Annual Convention of the A. I. E. E., to be held at the Hotel Cadillac, Detroit, Michigan, June 23-26, 1914, is rapidly nearing completion by the Convention Committee, of which Mr. Farley Osgood is chairman, and the Meetings and Papers Committee of the Institute. The complete program will be published in the June PROCEEDINGS. The order of events will be as follows:

TUESDAY, JUNE 23

10:00 a.m. President's Address.
10:45 a.m. Technical Session.
12:30 p.m. Section Delegates' Luncheon.
2:30 p.m. Automobile Trip.
8:15 p.m. Technical Session.

WEDNESDAY, JUNE 24

10:00 a.m. Technical Session.
12:30 p.m. Section Delegates' Luncheon.
2:30 p.m. Technical Session.
8:15 p.m. Presentation of Edison Medal and Past Presidents' Badges.
9:30 p.m. Dancing.

THURSDAY, JUNE 25

10:00 a.m. Technical Session.
12:30 p.m. Section Delegates' Luncheon.
2:30 p.m. Boating, Golf, Tennis, Baseball, etc.
8:15 p.m. Boat Ride.

FRIDAY, JUNE 26

9:00 a.m. Board of Directors' Meeting.
10:00 a.m. Technical Session.
2:30 p.m. Conference of Officers and Section Delegates.

## Second Institute Lecture on Electromagnetic Theory, by Dr. M. I. Pupin, May 6, 1914

The second of the series of two lectures by Dr. Michael I. Pupin, professor of electromechanics in Columbia University, on "The Relation of the Electromagnetic Theory to the Science of Electrical Engineering of the Present Day," will be given in the auditorium of the Engineering Societies Building, New York, on Wednesday evening, May 6, 1914. The first lecture was given on April 29.

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There has been a considerable misunderstanding of the relation of the work of Clerk Maxwell and the electromagnetic theory to the science and practise of electrical engineering of the present day, and Dr. Pupin has planned to show in these lectures how far the electrical science could have developed without Maxwell's work and along what lines there would have been no development without this work.

The recent advances in electrical engineering, including radiotelegraphy and radioactivity, he finds are much more dependent upon Maxwell's work than that type of engineering which may be called heavy-current engineering. It is curious that a great many engineers are daily making use of fundamental principles in electrical engineering, believing firmly that they are practising the electromagnetic theory of Maxwell, when they are not. The lectures are intended to bring out the points of contact between Maxwell's electromagnetic theory and the ordinary or less broad electromagnetic theory which serves as the foundation of electrical engineering today.

The lectures are given under the auspices of the Institute's Committee on Technical Lectures, and are open to the general engineering public.

## Pacific Coast Convention, Spokane, September, 1914

The 1914 Pacific Coast Convention will be held in Spokane, Wash., in September, the exact dates to be announced later. President Mailloux has appointed the following Convention Committee:

D. L. Huntington, chairman,
John B. Fisken, vice-chairman,
H. B. Peirce, secretary, all of Spokane.
C. S. MacCalla, Spokane.
H. A. Shearer, Spokane.
J. W. Hungate, Spokane.
S. E. Gates, Spokane.
E. R. Northmore, Los Angeles, Cal.
C. G. Pyle, Los Angeles, Cal.
G. R. Murphy, San Francisco, Cal.
A. H. Halloran, San Francisco, Cal.
G. P. Nock, Portland, Ore.
R. F. Monges, Portland, Ore.
S. C. Lindsay, Seattle, Wash.
A. A. Miller, Seattle, Wash.
E. M. Breed, Vancouver, B. C.
F. D. Nims, Vancouver, B. C.
Max Hebgen, Butte, Mont.

This committee is already actively at work through various sub-committees, including the Committee on Papers, of which Mr. John B. Fisken, chairman of the Spokane Section, is chairman.

The Northwest Electric Light and Power Association will hold its convention in Spokane at the same time, and the respective committees will coöperate and will probably arrange for one or more joint sessions.

Committees on Finance, Transportation, and Entertainment, composed of members of the Spokane Section, have been appointed, and will coöperate with similar committees from the N. W. E. L. & P. A. Additional information regarding plans and program will be printed in later issues of the PROCEEDINGS.

## Revised Standardization Rules

The revision of the Standardization Rules, on which the Standards Committee has been working for more than two years, is nearing completion, and it is expected that the preliminary draft will be in print by May 10. Owing to the very considerable expense of sending copies of this draft to the entire Institute membership, the Standards Committee has voted to have copies sent on request to those who are willing to give the proposed rules their immediate attention and to send in suggestions or criticisms. Applications may be sent to F. L. Hutchinson, Secretary, A. I. E. E., 33 West 39th Street, New York.

A number of copies will be sent to the secretaries of the San Francisco and Chicago Sections in order to save time in correspondence. Members residing in these districts may make direct ap-

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plication to these secretaries, as follows: Mr. A. G. Jones, Secretary, San Francisco Section, 819 Rialto Building, San Francisco, Cal.; Mr. E. W. Allen, Secretary, Chicago Section, 1028 Monadnock Building, Chicago, Ill.

Owing to the very short time remaining before the presentation of the revised rules to the Board of Directors at the June Convention, suggestions to be considered must be received by the undersigned not later than June 10.

When the rules are finally approved they will be printed, in the PROCEEDINGS or otherwise, and distributed to the entire membership of the Institute.

C. A. ADAMS,
Secretary, Standards Committee,
Address: Harvard University,
Cambridge, Mass.

## Pittsburgh Meeting of the A. I. E. E., April 9-10, 1914

The 293d meeting of the Institute was held in Pittsburgh, Pa., at the Fort Pitt Hotel, on April 9 and 10, 1914, under the auspices of the Committee on the Use of Electricity in Mines and the Pittsburgh Section. This is the second year that such a meeting has been held in Pittsburgh in April, devoted to the subject of electricity in mines.

The first session was opened on Thursday morning, April 9, with a short address by Mr. Wilfred Sykes, chairman of the Committee on Use of Electricity in Mines, on "The Regulation of Electrical Installations in Mines." The papers were presented in accordance with the program published in the April PROCEEDINGS. Reports of the discussions on these papers will appear in future issues of the PROCEEDINGS.

On Thursday afternoon, following the presentation and discussion of Mr. H. O. Swoboda's paper on portable electric lamps, there was a discussion on regulations governing electrical installations in mines, based on the German, English, and Pennsylvania laws, the rules proposed by the Bureau of Standards, Washington, D.C., and the rules proposed by the American Mining Congress. All of these rules and regulations had been reprinted by the Institute and distributed at the meeting. Among those who took part in the discussion at this time and on the next afternoon were Messrs. Clark, C. W. Beers, E. M. Hewlett, J. P. Clayton, C. M. Means, J. S. O'Donovan, Thomas, A. S. Biesecker, A. M. Dudley, Newton, A. F. Nesbitt, C. G. Braehm and Graham Bright.

On Thursday evening there was an informal Dutch dinner at the Fort Pitt Hotel. Professor C. F. Scott, past president of the Institute, spoke on the growth of the electrical industry.

The presentation and discussion of prepared papers was concluded with the session on Friday morning, and the discussion on laws and rules governing electrical installations in mines was finished in the afternoon. This ended the regular sessions of the meeting.

Saturday, April 11, was devoted to visits of inspection by the members and guests to various industrial plants in the vicinity of Pittsburgh.

## Convention of Michigan Section, N.E.L.A., June 17-20, 1914

The convention of the Michigan Section of the National Electric Light Association, June 17-20, 1914, will cover the following itinerary:

Leave Detroit, June 17, 5:00 p.m., D. and B. steamer.

Arrive Buffalo, June 18, 9:00 a.m.

Arrive Niagara Falls, June 18, 10:30 a.m., Electric Railway.

Leave Niagara Falls, June 18, 3:30 p.m., Gorge Route Railway.

Leave Youngstown, June 18, 6:00 p.m., steamer *City of Rochester*.

Pass through the Thousand Islands, commencing 6:00 a.m., June 19, arriving at Ogdensburg 10:00 a.m.

Leave Ogdensburg, June 19, at noon. steamer *City of Rochester*.

Arrive Toronto, June 20, 8:00 a.m.

Leave Toronto, June 20, 8:30 a.m., special train, C. P. Ry.

Arrive Detroit, June 20, 3:30 p.m.

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As this cruise ends in Detroit shortly before the opening of the A. I. E. E. Convention on June 23, the officers of the Michigan Section N. E. L. A. have invited any members of the Institute who may wish to do so, to participate in the trip. The price of tickets from Detroit to Ogdensburg, Toronto, and return, will be $30 per person, which will cover all traveling expenses except meals on board Detroit and Buffalo steamer, at Niagara Falls, and on train from Toronto to Detroit. The Michigan Section of the N. E. L. A. will prorate the fare for any part of the trip to members of the Institute. The fare from Youngstown to Ogdensburg, to Toronto, to Detroit, will be $22; and from Ogdensburg to Toronto, to Detroit, the fare will be $15.

All those who intend to take this trip should write to Mr. Herbert Silvester, secretary of the Michigan Section N. E. L. A., 18 Washington Boulevard, Detroit, Mich.

## Directors' Meeting, New York, April 7, 1914

The regular monthly meeting of the Board of Directors was held in New York on Tuesday, April 7, 1914.

There were present: President C. O. Mailloux, New York; Past-President Ralph D. Mershon, New York; Vice-Presidents A.W. Berresford, Milwaukee, Wis., S. D. Sprong and H. H. Barnes, Jr., New York; Managers N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York, L. T. Robinson, Schenectady, N. Y.; Treasurer George A. Hamilton, Elizabeth, N. J.; and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $10,312.16 was ratified.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred one member of the Institute to the grade of Fellow and two to the grade of Member, elected five applicants as Members and 57 as Associates, and ordered the enrolment of 35 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

A considerable amount of other business was transacted by the Board, reference to which will be found under proper headings in this and future issues of the PROCEEDINGS.

## Recommended for Transfer, March 31, 1914

The Board of Examiners, at its regular monthly meeting on March 31, 1914, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

TO THE GRADE OF FELLOW

ROPER, D. W., Assistant to Chief Engineer, Commonwealth Edison Co., Chicago, Ill.

TO THE GRADE OF MEMBER

EWING, DRESSEL D., Asst. Prof. Electrical Engineering, Purdue University, LaFayette, Ind.

LANIER, ALEXANDER C., Designing Electrical Engineer, Westinghouse Electric & Mfg. Co., Pittsburgh, Pa.

LIGHTFOOT, EDWIN N., Engineer, Cutler-Hammer Mfg. Co., New York, N. Y.

WENNER, FRANK, Associate Physicist, Bureau of Standards, Washington, D. C.

WHIPPLE, CYRUS A., General Superintendent, Municipal Light & Water System, Eugene, Ore.

## Transferred to the Grade of Fellow April 7, 1914

The following Member was transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on April 7, 1914.

PENDER, HAROLD, Professor of Electrical Engineering, Massachusetts Institute of Technology, Boston, Mass.

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### Transferred to the Grade of Member April 7, 1914

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on April 7, 1914.

BOLTON, FRANK C., Professor of Electrical Engineering, A. & M. College of Texas, College Station, Texas.

WINETRAUB, ADOLPH I. M., Resident Engineer, General Electric Co., Havana, Cuba.

### Members Elected April 7, 1914

BRAGA, EDUARDO DE A., Commissioned by the Brazilian Government, Rio de Janeiro, Brazil; res., 1335-15th St. N. W., Washington, D. C.

CLENDENIN, J. C., Assistant Engineer, General Electric Co.; res., 86 Ocean St., East Lynn, Mass.

HOOD, SAMUEL BINGHAM, Superintendent of Distribution, Toronto Electric Light Co. Ltd.; res., 229 Havelock St., Toronto, Ontario.

SHAW, THOMAS, Engineer, American Telephone & Telegraph Co., 15 Dey St., New York, N. Y.

WALLACE, JOHN NAPIER, Electrical Engineer, Bell Telephone Mfg. Co., Antwerp, Belgium.

Total 5

### Associates Elected April 7, 1914

ALBRECHT, AUGUST H., Engineering Dept., Wagner Electric Mfg. Co., 6400 Plymouth Ave., St. Louis, Mo.

ANDREW, WILLIAM M., Engineering Salesman, Canadian Westinghouse Co. Ltd., Traders Bank Bldg., Toronto, Canada.

APPLEGATE, KENNETH POMEROY, Engineering Dept., Hartford Electric Light Co.; res., 54 Main St., Hartford, Conn.

ARTHUR, M. WILSON, Salesman, Railway and Lighting Dept., Westinghouse Electric & Mfg. Co., 1107 Traction Bldg., Cincinnati, Ohio.

BAGLEY, ROY C., Chief Electrician, Hansell Elcock Co.; res., 3549 Indiana Ave., Chicago, Ill.

BALL, WILLIAM J., Secretary, Tri-City Electric Co., 1529-1531 Third Ave., Moline, Ill.

BARNARD, JOHN A., Central Station Work, Philadelphia Electric Co.; res., 770 S. Broad St., Philadelphia, Pa.

BERRY, ROBERT MARTIN, Electrical Engineer, Bedford City, Va.

BUNN, DAVID MARTIN, Construction Superintendent, Appalachian Power Co., Bluefield, W. Va.

CLARK, WALTER C., Supt. Light & Water Systems, Bunker Hill & Sullivan M. & C. Co., Kellogg, Idaho.

CORNELL, GEORGE B., JR., Superintendent, Yonkers Electric Light & Power Co.; res., 796 Palisade Ave., Yonkers, N. Y.

CORY, FRED C., Power Specialist, Toledo Railways & Light Co.; res., Y. M. C. A., Toledo, Ohio.

CRAMPTON, FAUST F., Patent Attorney, Owen, Owen & Crampton, Nicholas Bldg., Toledo, Ohio.

DAVIES, W. P., Construction Foreman, General Electric Co.; res., 1417 Albany St., Schenectady, N. Y.

DEEL, GEORGE R., Wireman, Isthmian Canal Commission, Corozal, C. Z.

DUNN, HARRY A., Superintendent of Power, Mexican Light & Power Co. Ltd., Necaxa, Puebla, Mexico.

FORCE, HENRY H., Chief Electrician, Stanley Works; res., 60 Vine St., New Britain, Conn.

FRANCIS, LESLIE L., Electrical Engineer, Union Traction Co., Independence, Kan.

FURLONG, WILLIAM REA, Lieutenant, United States Navy, Navy Department, Washington, D. C.

GILL, MURRAY F., Estimator and Material Clerk, Texas Power & Light Co., Dallas, Texas.

GILLETT, OMAR G., Construction Foreman, Engineering Dept., General Electric Co., 30 Church St., New York, N. Y.

GOLDMAN, OTTO B., Contracting Engineer, 303-4 Lewis Bldg.; res., 217 Grant St., Portland, Ore.

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GRAHAM, FRANK A., Engineer, Electrical Engineering Dept., Kansas City Electric Light Co., 1500 Grand Ave., Kansas City, Mo.

GRAY, HERBERT JOHN, Sales Agent, Canadian General Electric Co. Ltd., 1065 Pender St. W., Vancouver, B. C.

HAMILTON, JAMES T., Electrical Dept., N. Y. N. H. & H. R. R. Co., 1723 Matthews Ave., Van Nest, N. Y.; res., Howard, R. I.

HARRINGTON, Louis J., Electrical Draftsman, Pullman Co. Pullman Car Works.; res., 537 E. 112th St., Chicago, Ill.

HOBSON, ARTHUR J., Foreman Electrical Construction, Isthmian Canal Commission, Gatun, C. Z.

HUMMEL, PHILIP BIRCHFIELD, Instrument Man and Tester, Long Island R. R. Co., Jamaica; res., Hollis Court Blvd., Queens, L. I., N. Y.

LAPP, JOHN S., Secretary, Locke Insulator Mfg. Co., Victor, N. Y.

LEWIS, ROY HOWARD, Chief of Operating Dept., Cuyuna Range Power Co., Brainerd; res., Sylvan, Minn.

MACINTOSH, JOHN M., Assistant in charge Electric Repair Shops, Rio Janeiro Tramway, Light & Power Co. Rio de Janeiro, Brazil.

MERRIMAN, HORACE O., First Assistant Engineer, Hamilton Hydro-Electric Department, City Hall, Hamilton, Ont.

MEYER, ARTHUR A., Assistant Electrical Engineer, Edison Illuminating Co.; res., 474 Sylvester Ave., Detroit, Mich.

MYRICK, JESSE CLARENCE, Foreman, Isthmian Canal Commission, Balboa, Canal Zone.

NORTON, Keller E., Member of firm, Cox-Norton & Co., Coldwater, Mich.

OLSEN, BERNHARD, Motor Agent, General Electric Co., 402 Paulsen Bldg.; res., 214 W. 8th Ave., Spokane. Wash.

O'NEILL, CHARLES F., Sales Engineer, Westinghouse Electric & Mfg, Co., New York; res., 1 Kenilworth Place. Orange. N. J.

PAGET, JOSEPH HAROLD, Meter Engineer, British Columbia Electric R. R., Vancouver, B. C.

PALMBLADE, RAYMOND F., Engineer, Peoria Railway Co., 634 S. Adams St.; res., 1331 Hamilton Blvd., Peoria, Ill.

PATTERSON, JAMES GEORGE, Assistant Engineer, New England Telephone & Telegraph Co., 50 Oliver St., Boston, Mass.

PERRY, WILLIAM JOHN, Electrical Wireman, Isthmian Canal Commission, Corozal, C. Z.; res., Brookings, S. D.

PLACE, ALFRED G., Assistant Chief Electrician, Youngstown Sheet & Tube Co.; res., 517 Yale Ave., Youngstown, Ohio.

POWELL, WINFRED T., Telephone Engineer, Automatic Electric Co., Chicago, Ill.

RAMM, THEODORE D., Asst. to Electrical Engineer, St. Paul Gas Light Co., St. Paul.

RICE, LEVERETT E., Electrical Engineer, Scranton Electric Co.

RUSSELL, FOSTER, Commercial Engineer, Washington Water Power Co.; res., 2702 E. 8th Ave., Spokane, Wash.

SCOTT, HUGH C., Chief Electrician, Hampton Co; res., 17 Summer St.. Easthampton, Mass.

SIMMONS, WILLIAM B., Engineering Dept., American Transformer Co.

STACY, WILLIAM K., Assistant to Electrical Engineer, Washington Water Power Co.; res., 1507 S. Cedar St., Spokane, Wash.

STEGMAIER, CHARLES H., Salesman, Central Union Telephone Co., 235 S. Meridian St., Indianapolis, Ind.

SUMMERS, ORRAN BERTRAM, Construction Dept., Alabama Power Co., Lincoln.

THOMPSON, RALPH E., Superintendent, Gillette Safety Razor Co., Boston; res., 35 Winthrop Road, Brookline, Mass.

THOMPSON, R. M., Engineering Dept., Hydro-Electric Power Commission, 709 Continental Life Bldg., Toronto, Ontario.

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UGGLA, WILHELM ROBERTS, Computor, Svenska Turbinfabriks Aktiebolaget Ljungstrom, Finspong, Sweden.

WEBBER, EDWIN MOREY, Sales Engineer, Wagner Electric Mfg. Co.; 1624 Marquette Bldg.; res., 5608 Michigan Ave., Chicago, Ill.

WORTHINGTON, EDWARD H., Sales Engineer, The Destructor Company, Peoples Gas Bldg., Chicago.

WYCKOFF, HOMER J., Cable Tester on Underground Transmission, Edison Illuminating Co.; res., 931 Y. M. C. A., Detroit, Mich.

Total 57

## Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before May 30, 1914.

Adams, O. F., Toronto, Ont.
Andrews, S. W., Portland, Ore.
Benzing, H. J., Philadelphia, Pa.
Blymyer, L. W., San Francisco, Cal.
Boyd, A. P., E. Pittsburgh, Pa.
Brandes, W. P. Magnolia, W. Va.
Broili, F. (Member), Virginia City, Nev.
Brown, E. W., Pittsburgh, Pa.
Brug, F. A., Cleveland, Ohio.
Carron, H. G., Detroit, Mich.
Charley, R. M., E. Pittsburgh, Pa.
Cooley, E. H., Washington, D. C.
Crothers, H. M., Madison, Wis.
Davidson, W. F., Ann Arbor, Mich.
Dawson, W. E., Portland, Ore.
de Boeck, F., Calgary, Alta.
de Laval, C. G. H., Lynn, Mass.
Dinion, N., New Haven, Conn.
Dodge, H. P. (Member), Toledo, Ohio.
Eckley, G. M., Pittsburgh, Pa.
Eddington, A., Chelmsford, England.
Enloe, E., Spokane, Wash.
Ferrier, T., Toronto, Ontario.
Flanders, M. M., Washington, D. C.
Framji, K. G. (Member), Calcutta, India.
Grimsdick, E. P., Calcutta, India
Harrington, C. O., Pittsburgh, Pa.
Hegerty, P. F., Pittsburgh, Pa.
Hendrickson, G. F., Colo. Springs, Colo.
Holsey, T. E., Spokane, Wash.
Ilsley, L. C., Pittsburgh, Pa.
Jefferies, E. S., Hamilton, Ont.
Johnson, C. W., Detroit, Mich.
Johnson, O. H., St. Paul, Minn.
Kallevang, E. J., De Kalb, Ill.
Kersey, G. B., Chicago, Ill.
Lidbury, F. A., Niagara Falls, N. Y.
Mallory, E. B. (Member), New York, N. Y.
Malott, C. G., La Fayette, Ind.
Marshall, A. C., Detroit, Mich.
Marshick, O. J., Detroit, Mich.
McClure, L. H., Hartford, Conn.
McCoy, T. E., Corozal, C. Z.
Melvin, C. E., New York, N. Y.
Miller, C. A., Tiffin, Ohio.
Morrissey, J. P., New York, N. Y.
Nyman, H. E., Detroit, Mich.
Outzen, A. N., Madison, Wis.
Paine, R. M., Vancouver, B. C.
Payne, T. H., Sweetwater, Texas.
Pernot, F. E., Berkeley, Cal.
Peters, J. F. (Member), E. Pittsburgh, Pa.
Rice, C. W., Schenectady, N. Y.
Roeber, E. F., (Member), New York, N. Y.
Rohr, C. A., New York, N. Y.
Schwarz, F. J., Schenectady, N. Y.
Scovel, H. W., Chicago, Ill.
Selleck, R. R., Cleveland, Ohio.
Shannon, J. F. (Member), Los Angeles, Cal.
Sharp, J. M., Takoma Park, D. C.
Spruance, F. D., Corozal, C. Z.
Teele, F. W. (Member), San Juan, P. R.
Thau, W. E., E. Pittsburgh, Pa.
Webster, S. T., St. Louis, Mo.
Westervelt, H. P., New York, N. Y.
Wilber, S. B., Worcester, Mass.
Willis, A. H., Erie, Pa.
Woodruff, C. H. (Member), Detroit, Mich.
Work, L., Pedro Miguel, C. Z.
Total 69

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### Students Enrolled April 7, 1914

6477 Fuller, W. D., Penna. St. College.
6478 Lawrence, G.W., Univ. of Toronto.
6479 Mackenzie, A.M., Univ. of Toronto.
6480 Richey, J. W., Penna. St. College
6481 DuMond, J.W.M., Throop Coll. Tech.
6482 Taylor, A.R., Univ. of Wisconsin.
6483 Jerry, A.E., Ohio Northern Univ.
6484 Allington, J. B., Cornell Univ.
6485 Scott, W. R., Cornell University.
6486 Wells, A. W., Throop Coll. Tech.
6487 Wright, A.W., Univ. of Virginia.
6488 Tallmadge, E. S., Univ. of Minn.
6489 Sweet, L. L., Syracuse University.
6490 Wilson, H.F., Rensselaer Poly. Inst.
6491 Curley, J.S., Rensselaer Poly. Inst.
6492 Gibson, T. A., Georgia Sch. Tech.
6493 Strecker, G. M., Colo. A.&M. Coll.
6494 Himmelsbach, J. R., Univ. of Wash.
6495 Dudley, A., Iowa State College.
6496 Ingram, J., Jr., Lewis Institute.
6497 Yerington, R. A., Univ. of Mich.
6498 Siegfried, E. W., Jr., Univ. of Pitts.
6499 Smith, W. H., N.C.A. & M. Coll.
6500 Hickman, G., Univ. of Pittsburgh.
6501 Gill, E. I., Univ. of Toronto.
6502 Fairbanks, F. B., Harvard Univ.
6503 Steinbeck, E. H., Univ. of Calif.
6504 Peart, J. D., Univ. of Toronto.
6505 Shultz, A. D., Penn. State Coll.
6506 Stillingsworth, D. J., Highland Park College.
6507 Becker, J. J., Mo. State Univ.
6508 Cole, H. L., Worcester Poly. Inst.
6509 Carpenter, G.W., Iowa State Univ.
6510 Cockrell, F. W., Univ. of Ill.
6511 Bartling, H. W., Univ. of Ill.

### Joint Engineering Dinner in Boston, March 4, 1914

The fifth joint engineering dinner in Boston was held March 4, at the City Club, under the auspices of the Boston Section of the American Institute of Electrical Engineers, with an attendance of about 230. Mr. N. J. Neall, chairman of the Boston Section, presided.

The speakers of the evening were Mr. Guy E. Tripp of the Westinghouse Electric and Manufacturing Company, who spoke on "The National Government and Business"; Dr. A. E. Kennelly of Harvard University, who spoke on "Results for the Engineering Fraternity Accomplished by the International Electrotechnical Commission"; and Dr. M. W. Franklin of the Sprague Electric Works, who spoke on "The Engineer's Position in our Present Civilization". President C. O. Mailloux of the American Institute of Electrical Engineers and President James Hartness of the American Society of Mechanical Engineers were present and brought officially the greetings of these national societies. Among the guests were President Charles O. Bond of the Illuminating Engineering Society and Mr. Calvin W. Rice, secretary of the American Society of Mechanical Engineers. Professor Harry E. Clifford of Harvard University was toastmaster.

These dinners have become a distinct feature of engineering activities in Boston and are conducted in rotation by the Boston Sections of the American Institute of Electrical Engineers, the American Society of Mechanical Engineers and the Boston Society of Civil Engineers, while invitations are extended to all engineers in Boston and vicinity.

### Past Section Meetings

#### Baltimore

The February meeting of the Baltimore Section was held in the physical laboratory of the Johns Hopkins University, on Friday evening, February 20. Mr. L. E. Barringer, who was to present a paper on "Insulating Materials," was unable to do so on account of illness.

Professor J. B. Whitehead gave a talk on the new nitrogen-filled tungsten lamps. A demonstration was given with two bulbs.

The attendance was 18.

#### Boston

The regular monthly meeting of the Boston Section was held at the Engineers' Club on March 19. A paper on

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"Protective Relays and their Relation to Continuity of Service" was presented by Mr. George A. Burnham, chief engineer of the Condit Electrical Engineering Company.

The meeting was attended by 50 members and visitors. Chairman N. J. Neall presided.

### Chicago

A joint meeting of the Electrical Section of the Western Society of Engineers and the Chicago Section A. I. E. E. was held Monday evening, February 23, with about 60 members and guests in attendance. Mr. C. H. Hill of the General Electric Company, Schenectady, N. Y., presented with lantern slide illustrations a description of "The Switchboards for the Control of the Panama Locks." This was followed by a motion picture showing the operation of the switchboard.

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The next joint meeting of the two societies was held Thursday evening, March 26, with about 100 members and guests in attendance. Mr. B. H. Glover, of the Underwriters Laboratories, read a paper on the duties and services of the laboratory, particularly as relating to electrical inspection.

### Cleveland

The regular meeting of the Cleveland Section was held in the Electricity Building at the Case School of Applied Science, on March 23, Mr. E. J. Edwards presiding. There were 48 members and visitors present.

Mr. L. P. Crecelius, of the Cleveland Railway Company, presented a paper entitled *Sixty-Cycle Synchronous Converters.* This was printed in the March, 1914, Proceedings. After the paper an interesting discussion took place, in which Messrs. Schuler, Burnham, Wallau, Yardley, Lewis, and Bale participated.

### Detroit-Ann Arbor

The Detroit-Ann Arbor Section held a meeting on March 13, in the New Engineering Building, University of Michigan, Ann Arbor. Professor A. R. Sawyer, the chairman, presided, and 52 members and visitors attended.

After the executive business had been transacted, the chairman introduced Professor John W. Langley, who spoke on "The Development of Electric Lighting." He was followed by Professor H. H. Higbie, who spoke on "Modern Types of Electric Lights." Professor Higbie's talk was illustrated by a display of practically every type of electric lighting unit.

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The next meeting of the Section was held at the Adcroft Club, in Detroit, on March 27. Chairman Sawyer presided, and the attendance was 59.

The speaker was Mr. Arthur Bessey Smith, consulting engineer, of Chicago, who presented an illustrated paper on "Automatic Private Telephone Exchanges, their Effectiveness and Efficiency." A general discussion followed.

### Indianapolis-LaFayette

The regular February meeting of the Indianapolis-LaFayette Section was held at the Indianapolis Chamber of Commerce, on February 20. Chairman O. S. More presided, and the attendance was 31.

The meeting was addressed by Mr. C. E. Hansell, assistant manager of The Esterline Company, who gave an illustrated talk on "Some Engineering Features of Integrating and Curve-Drawing Electric Meters." Mr. Hansell dealt with the different types of instruments, showing a large number of slides and illustrating the various types of construction and operation, taking up in particular the different types of ampere-hour meters and integrating wattmeters, as well as curve-drawing instruments of various kinds.

The meeting was of more than usual interest due to the particular applications which can be made of curve-drawing instruments, and the discussion along this line brought out many points of value.

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### Ithaca

The Ithaca Section held a meeting on October 30, 1913, in Franklin Hall. Professor George S. Macomber presided, and the attendance was 22. Professor Frederick Bedell addressed the Section on "Methods of Determining Alternating-Current Wave Forms." Many different methods were described, and their errors and advantages pointed out. A general discussion followed.

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The next meeting was held in the same place on November 14. Professor Bedell presided, and 35 were present. Mr. L. F. Fuller, of the Federal Telegraph Company, San Francisco, California, spoke on "Recent Developments in Wireless Telegraphy."

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At the meeting on December 12, Mr. E. B. Rowe, chief illuminating engineer of the Holophane Division of the General Electric Company, Cleveland, Ohio, gave a talk on "The Influence of Science on the Art of Illumination."

The attendance at this meeting was 115. Professor Macomber presided.

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On January 17 the annual banquet of the Ithaca Section, at which 126 were present, was held at the Ithaca Hotel. Mr. B. A. Behrend, of Boston, Mass., was the principal speaker. Professor E. L. Nichols, chairman of the Section, presided.

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The student division of the Ithaca Section enjoyed a novel program on February 7 and 9, when a four-cornered debate was held between four pairs of men from the senior class in mechanical engineering at Sibley College. The question debated was: "What is the best system for the New York, Auburn and Lansing Railroad to adopt on its line from Ithaca to Auburn?" The following systems were advocated by the respective parties: steam locomotives, the gasoline motor car system, the gasoline-electric motor car system, and the electric trolley system. The judges declared the advocates of the gasoline motor car system to be the winners in the debate. After this was announced a representative of the railroad stated that the gasoline motor car would probably be adopted. This has since been done.

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A meeting of the Ithaca Section was held on March 28, in Franklin Hall, when the speaker was Mr. Charles R. Underhill, electrical engineer of the Acme Wire Company, of New Haven, Conn. His subject was "The Theory and Practise of Electromagnets." Mr. Underhill showed the application of Maxwell's equations to the design of electromagnets, and discussed the limitations of the equations derived by S. P. Thompson.

Mr. F. H. Hibbard presided at this meeting, which was attended by 36 members and visitors.

### Los Angeles

The subject for the meeting of the Los Angeles Section on March 26, in the Temple Auditorium, was "Electricity as a Source of Heat." Mr. Max Loewenthal gave a review of the historical and commercial development of electrically heated appliances, illustrated by numerous experiments and moving pictures. Practically all of the modern cooking and heating appliances were exhibited.

Chairman E. R. Northmore presided. Forty members and 120 visitors, including many ladies, were present.

### Milwaukee

A meeting was held on February 11, in the club room of the Plankinton House, which was conducted by the Milwaukee Section of the A. S. M. E., the Milwaukee Section of the A. I. E. E. coöperating. A paper was presented by Mr. Percy C. Day, of the Falk Company, on the Wuest herringbone gears and their application.

Mr. E. P. Worden presided at this meeting. The total attendance was 107.

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The April meeting of the Milwaukee Section was held at the Plankinton House on the evening of April 8. The paper was given by Mr. F. T. Snyder, of the Metallurgic Engineering Company of Chicago. He chose for his subject "The Electric Furnace," paying particular attention to its application for cupola service. The lecture was illustrated by a number of slides giving various schemes of connections used on a-c. service and also by a number of slides illustrating various types of furnaces. Data were also given as to the hours of service and demands on the central station due to furnaces of different types. There was an audience of about 100 present, of whom 50 were Institute members. Chairman L. E. Bogen presided.

### Minnesota

The regular monthly meeting of the Minnesota Section was held Monday evening, March 16, at the Ryan Hotel, St. Paul, preceded by the customary dinner.

The first paper was presented by Mr. Herbert S. Whiton, of the Minneapolis General Electric Company, on "System Operation." With the aid of lantern slides Mr. Whiton explained the switching operation of the Byllesby system, which begins at the hydro-electric generating station at Taylors Falls, Minn., about 40 miles from Minneapolis. The current is transmitted to Minneapolis by two three-phase 50,000-volt lines. Distribution is made to the various substations in Minneapolis and St. Paul at 13,200 volts. Attention was directed to the peculiarly fluctuating conditions of the system, arising from the variations of the stage of water in the St. Croix River, from the natural fluctuation of the load in the Twin Cities, changing from hour to hour, and from the fact that the St. Paul steam generating plant also distributes steam for heating on a large scale, so that the kilowatt output of that plant varies considerably with the temperature. It is easily seen that a most careful day to day record must be kept, covering all these conditions, in order to operate the system with the greatest economy.

The next paper was "The Use of Electricity on Automobiles," presented by Mr. R. L. Lunt. While Mr. Lunt's paper presented some points relating to magnetos and the other electrical accessories now in use on automobiles, the greater part of it was devoted to the development of lead storage batteries. With the aid of lantern slides furnished by the Philadelphia Storage Battery Company, Mr. Lunt showed the important changes that had taken place in lead battery construction during the past six or eight years. The thickness of the lead grids has been steadily decreased, permitting the use of increased plate area in the same size of container. This has increased the battery's output materially without adding a proportionate amount of weight. The thin plate is equally serviceable, as chemical analysis has shown that the active material is affected only to a depth of 1/32 in., the rest of the material serving simply as a binder, and a reserve to provide for the unavoidable disintegration of the active material.

Chairman W. T. Ryan presided at this meeting. The total attendance was 33.

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## Past Branch Meetings

### University of Arkansas

The University of Arkansas Branch held a meeting on February 10, when Lieut. N. J. Wiley, U.S.A., made an address on the work of the Signal Corps of the United States Army.

At the meeting of the Branch on March 9, Professor W. B. Stelzner gave a talk on "Electrification"; Mr. C. W. Hayes a talk on "The Chemical Analysis of Rubber Insulation"; and Mr. J. E. Bell read an abstract of the recent Institute paper *Sources of Direct Current for Electrochemical Processes*, by F. D. Newbury.

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### Bucknell University

The Bucknell University Branch held a meeting on January 20, when Mr. F. O. Schnure gave a lecture on the Keokuk hydroelectric plant, illustrated with lantern slides.

### University of California

At the meeting of the University of California Branch on January 28, Mr. L. M. Clement presented a paper on "Wireless Telegraphy".

At the meeting on February 11 a paper was presented by Messrs. J. E. Zeile and C. B. Merrick, on the Standardization Rules of the A. I. E. E.

Dr. Meade of the medical department of the university presented a paper at the meeting on February 26, on "First Aid to the Injured". The paper was supplemented by practical demonstrations of first-aid methods.

Messrs. H. H. Buttner and C. C. Brown presented the paper on March 18, on the subject "Electric Propulsion of the United States Naval Collier *Jupiter*".

The next meeting of the Branch was held on March 25, when Messrs. H. B. Henderson and M. C. Souza read a paper on "Electric Railway Development".

At the meeting on April 8 Mr. P. R. Parrish read a paper on "Air Condensers", using a model which had been made by himself and Mr. A. H. Wurts. Mr. Wurts then read a paper on the laws and regulations governing the use of forest lands for power purposes.

### University of Cincinnati

The University of Cincinnati Branch held a meeting on February 17, when Mr. Parker H. Kemble of the Union Gas and Electric Company made an address on "The Public, the Utility Commission, and the Company", defining their relations to each other.

At the next meeting of the Branch, on March 24, Mr. Hunt, research engineer for the Delco plant, of Dayton, Ohio, gave a talk on the development of the Delco electric ignition, lighting and motor-starting systems for gasoline automobiles.

### University of Colorado

The University of Colorado Branch held a meeting on February 4, when a talk on "The Oil Industry" was given by Dr. F. E. Knock, superintendent of the Florence, Colorado, refinery of the United Oil Company.

At the meeting on February 18 Mr. H. S. Russell, chief engineer for the Denver Gas and Electric Company, made an address on "Distribution of Central Station Energy".

Mr. H. C. Bullock, of the Denver office of the Westinghouse Electric and Manufacturing Company, was the speaker at the meeting on March 4. His subject was "Industrial Motor Applications".

At the next meeting of the Branch, on March 18, Mr. George E. Luther, of the Denver Branch of the Electric Storage Battery Company, gave a talk on "The Storage Battery", describing the various installations and classes of work to which storage batteries are applied. Many illustrative lantern slides were shown.

At the meeting of the Branch on April 1, Mr. H. C. Biglin of the Western Electric Company gave a talk on the student apprentice courses offered by his company, with a detailed description of the three courses open to engineering graduates and the opportunities for men in that line of work.

### Colorado State College

The Colorado State College Branch held a meeting on January 29. Mr. L. M. Klinefelter gave a talk on "The Development of the Central Station". Especial emphasis was laid on the progress in the construction of electrical measuring instruments. Additional

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information on the same topic was given by Professor Rankin.

At the meeting on February 26 Mr. Klinefelter presented a paper on "The Development of the Electric Light".

The next meeting was held on March 26, when Professor Macdonald presented a paper on "The Niagara Hydro-electric Power Plant and Its Advantages".

The annual dinner of the Branch was held on the evening of March 29, followed by an informal dance given by Professor Rankin.

### Highland Park College

The Highland Park College Branch held a meeting on January 14, devoted to the subject of electric railways. The following papers were presented: S. W. Palmer, "The Brill Motor Truck"; E. R. Witzel, "What is the Standard Voltage, and Why?"; H. E. Johnson, "Motor Designs"; E. J. Stellingsworth, "Motor Ratings"; and W. Roush, "The Third-Rail Systems and Overhead Trolleys".

At the meeting on January 28, the discussion of this subject was continued, the following papers being presented: J. Gailunas, "The Gramme Armature and Interpole Motors"; E. E. Gould, "Compressed Air Brakes"; and E. B. Williams, "Alternating-Current Motors".

The meeting on February 11 was devoted to the subject of refrigeration. The papers were as follows: F. P. Boone, "Mechanical Refrigeration"; R. Sneddon, "The Parsons Quick Freeze System"; J. C. Shutt, "The Compression System of Refrigeration"; and E. E. Gould, "Methods of Freezing, with Special Reference to the Can System".

At the meeting of the Branch on February 25, a paper was presented by Mr. T. B. Genay, chief engineer of the Des Moines Gas Company, on "Reducing Boiler Fuel in Water Gas Manufacture".

The next meeting of the Branch was held on March 11, when the following papers were presented: J. Gailunas, "The Design of Water Turbines"; R. B. Hale, "The Development on the Ocoee River by the Tennessee Power Company"; and E. B. Williams, "The Keokuk Dam and Power House".

### University of Iowa

At the meeting of the University of Iowa Branch on January 13, Mr. O. L. Johnson of the Benjamin Electric Manufacturing Company, of Chicago, gave a talk on "Illuminating Engineering".

On January 27, Mr. Glen W. Carpenter presented an illustrated paper on "Power Plants of the Upper Iowa Power Company".

At the meeting on February 10 a paper was presented by Mr. H. C. Blackwell of the Peoples Light Company of Davenport, Iowa, on "Rate Making from the Standpoint of the Public Utility".

At the meeting of February 24, Mr. J. Ralph Eyre spoke on "Church Lighting".

The next meeting of the Branch was held on March 10, when an illustrated lecture on "The Edison Storage Battery", prepared by Thomas A. Edison and H. H. Smith, was presented by Mr. J. H. Carmichael. The lecture was furnished by the National Electric Light Association.

### Iowa State College

The Iowa State College Branch held a meeting on February 25, when Messrs. Harry Porter and C. E. Ide abstracted the recent Institute papers on the electrical equipment of gasoline automobiles. This was followed by a general discussion on the subject, led by Mr. B. A. Cole.

### University of Kansas

At the meeting of the University of Kansas Branch on December 17, 1913, the speakers were several members of the senior class. Mr. J. R. Smith des-

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cribed the equipment of the power houses of the Metropolitan Street Railway of Kansas City, Missouri. Messrs. A. J. Fecht and Joseph Segal described the experiences of the seniors on their inspection trip to Keokuk and St. Louis.

At the meeting on February 18, Mr. O. H. Horner gave a talk on the municipal electric plant of KansasCity, Kansas.

February 25 was "Electrical Engineers' Day" at the engineering school of the University of Kansas. The opening address of the morning session was given by Dean Walker, followed by a paper on "The 'Safety First' Movement in Railway Operation", by Professor C. C. Williams. In the afternoon the following papers were presented: "Recent Developments in the Design and Manufacture of Induction Motors", by W. F. Barnes; "The Self-Starting of Synchronous Motors", by A. J. Fecht; "The Electrical Equipment of a Large Mercantile Establishment", by H. C. Henrici; "The Place of Telephony in Electrical Engineering", by H. C. Lauderback, and "Mine Haulage", by L. R. von Stein. In the evening a dinner was given at the Eldridge House, with brief talks by several of the professors and members of the Branch.

KANSAS STATE AGRICULTURAL COLLEGE

The Kansas State Agricultural College Branch held a joint meeting on April 3 with the student branch of the A. S. M. E. The following program was given: "Rectifiers", by H. E. Butcher (accompanied by demonstration of apparatus); a demonstration of nitrogen-filled lamps, by G. B. McNair; "The Buckeye Locomobile", by James Moss; "Electric Sparks", H. W. Stokebrand; "A Small Oil Refinery", by N. M. Hutchinson. The program was followed by separate business meetings of the two organizations.

UNIVERSITY OF KENTUCKY

The meeting of the State University of Kentucky Branch on April 1 was addressed by Mr. W. M. Hannah, of the General Electric Company, on the subject of "Standard Equipment". He spoke of the evolution of electrical apparatus, especially its rapid growth in the last few years, and outlined the details of the modern power plant. Mr. G. C. Hyde, engineer of the Kentucky Utilities, then made a few remarks on transmission lines and insulators.

LAFAYETTE COLLEGE

The Lafayette College Branch held a meeting on February 2, when a paper on "Line Surges" was presented by Mr. J. H. Kerrick, and a paper on "Submarine Telegraphy" was presented by Mr. P. M. Lee.

At the meeting on February 9 two papers were presented: "Repair of High-Tension Lines in Operation", by M. H. Simmons; "Diesel Engines for Power Plants", by H. S. Conklin, Jr.

On February 11 four papers were presented: "Railroad Telephones", by J. H. Kennedy; "Remote Control Apparatus", by W. J. English, Jr.; "Complete Tests of an Alternating-Current Machine", by V. A. Davison; "Requirements of Incandescent Lighting", by R. S. Soles.

At the meeting on February 16 the program was as follows: "The Wilkes-Barre, Pennsylvania, Gas and Electric Company", by C. R. Johman; "The Keokuk Plant", by W. B. Killough; "Outline of Panama Electric Equipment", by E. E. Smith.

On February 23 two papers were presented: "Ward Leonard Systems", by R. D. McManigal; "Tallulah Falls and Hales Bar Hydroelectric Plants", by R. K. Laros.

The program at the meeting on March 2 was as follows: "The Edison Storage Cell", by W. H. Powell; "The Electric Truck", by H. W. Bailey; "Alternating-Current Motors for Machine Tool Drive", by L. Jefferson.

On March 4 these papers were read: "Brush Arc Machines", by F. L. Kolb; "Thomson-Houston Arc Machines", by H. C. Mitchell; "Multiple Telephone Exchange", by W. W. Thompson.

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At the next meeting of the Branch, on March 9, four papers were read: "The Lackawanna and Wyoming Valley Railroad", by G. P. Ellis; "History and Development of the Storage Battery", by J. R. Clymer; "Electricity from Culm Piles", by J. W. Magee; "Electric Locomotives", by L. C. Van Inwegen.

### Lehigh University

The Lehigh University Branch held a meeting on February 13. The first speaker was Mr. H. M. Poust of the senior class, who gave an account of the inspection trip of the senior electrical engineering students following the Christmas holidays. Mr. J. Franklin Stevens of Philadelphia then made an address on the development of the American Institute of Electrical Engineers and what it stands for.

The next meeting of the Branch was held on March 24. Mr. J. S. Williamson of the senior class read a paper on "Mercury Vapor Turbines", describing the economies made possible by this new development. Mr. C. R. Underhill, chief electrical engineer of the Acme Wire Company, of New Haven, Conn., spoke on "Electromagnets", explaining how the laws discovered by Maxwell could be applied to all sorts of magnets if the effects of leakage flux were considered. He demonstrated his facts by many interesting experiments.

### University of Maine

The University of Maine Branch held a meeting on February 26. Mr. W. E. Bowler was elected vice-president in place of Mr. P. B. Sheridan, resigned. Mr. F. S. Jones read a paper on "The Central Maine Power Company", and Mr. H. R. Clark spoke on some of the papers in the early volumes of the A. I. E. E. Transactions.

### University of Michigan

The University of Michigan Branch held a meeting on February 12, when Mr. Conant presented a paper on "Commercial Uses of the Storage Battery". Mr. W. B. Kopfer resigned as secretary and Mr. E. T. Anderson was elected to take his place.

At the meeting of the Branch on March 5, Professor B. F. Bailey gave an illustrated talk on the spring inspection trip of the senior electrical engineering students.

The speaker at the meeting on March 16 was Mr. E. H. Jacobs, of the General Electric Company, who gave an illustrated lecture on the Panama Canal electrification and the methods of electric control. This was a meeting of all the engineering students, held under the auspices of the A. I. E. E. Branch.

At the next meeting, on April 2, Mr. Arthur Bessey Smith of the Automatic Electric Company, of Chicago, presented a paper on "Automatic Telephones".

### University of Missouri

The University of Missouri Branch held a meeting on January 19, which was devoted to a discussion of phase transformation. Mr. R. G. Thompson described several methods of changing two-phase to three-phase and vice-versa, comparing the merits of the different plans. Mr. C. M. Laffoon took up the subject of utilizing polyphase power to best advantage for large single-phase loads, and of deriving polyphase power from a single-phase supply. Rotary phase-converters were described.

At the meeting on February 9 the subject of remote control of electrical apparatus was discussed. Mr. L. D. Macom described an automatic remotely controlled substation in Detroit. Mr. A. L. Strother described the electrical system which controls the operation of the lock-gates, valves and other apparatus on the Panama Canal. Mr. Luscombe described several systems of multiple unit railway motor control. A general discussion followed.

On February 23 a talk on "Telephone Engineering" was given by Mr. E. W. Kellogg.

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At the meeting on March 10, Mr. H. M. Tickle reported the results of tests that he and his brother, Mr. Richard Tickle, had been carrying on to determine the merits of electric fans in connection with hot-air house furnaces. The fan was placed in the cold air intake. It was found that the house could be heated more quickly with the fan, and that it could be maintained at the same temperature with slightly less coal, but with average prices for coal and electricity the saving in coal was not sufficient to pay for the cost of running the fan. The subject of railway electrification was then taken up by Messrs. C. M. Duren and E. B. Smith. Mr. Smith made a comparison of the three principal systems of transmission. Mr. E. V. Gmeiner resigned as treasurer of the Branch and Mr. F. W. Anderson was elected to succeed him for the remainder of the school year.

At the next meeting, on March 23, the subject was "Street Lighting". The speakers who discussed different divisions of the subject were Messrs. L. E. Knapp, J. A. Colvin and F. H. Templeton.

The subject considered at the next meeting of the Branch, on April 7, was "Electricity in Mining". Mr. G. S. Dring discussed the applications of electricity in coal mining, and Mr. P. J. Smith dealt with the subject in relation to metal mining, showing how various economies had made it profitable to utilize much lower grade ores than formerly, and how electric power had contributed to this economy.

## Personal

MR. FREDERICK H. COBLE has been appointed test engineer of the Pacifis Light and Power Corporation. Loc Angeles, California.

MR. GEORGE B. SCHLEY has formed with Mr. Arthur M. Hood, whose assistant he has been since 1911, a partnership under the firm name of Hood and Schley, for the practise of patent, trademark and copyright law. The offices of the firm are at 908 Hume-Mansur Building, Indianapolis, Indiana.

MR. S. R. BLAKEMAN, who for the past four years has been superintendent of the Senatobia, Miss., electric light and water plant, has been made superintendent of the Water and Electric Light Department of the city of Dyersburg, Tenn. Mr. Blakeman was graduated from Purdue University in 1909.

MR. MORTIMER FREUND, who is associated with P. R. Moses, consulting engineer, has been in Vancouver, B.C., during the winter and spring, in connection with the electrical and mechanical installations for the large department stores being erected by the Hudson's Bay Company in Vancouver and Victoria, B.C. While there he was called in as consultant in connection with similar equipment for the new hotel being erected in Vancouver by the Canadian Pacific Railway.

MR. F. N. JEWETT, sales manager of the Wagner Electric Manufacturing Company, has had to relinquish temporarily the duties of his position, because of a recent nervous collapse. He will, however, retain his connection with the Wagner Company, in the capacity of assistant to the executive officers. His condition is showing satisfactory, though slow, improvement, with the assurance of complete recovery in time. Mr. Jewett, who was graduated from Cornell University in 1893, has been connected with the Wagner Company since 1906, when he was made manager for the Chicago district.

MR. E. W. P. SMITH has been appointed city electrician of Cleveland, Ohio. After graduation from Colorado College in 1908, and a year of operating experience in the West, Mr. Smith entered the employ of the Westinghouse Electric and Manufacturing Company, in the railway engineering department.

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Mr. Smith was afterwards employed by the city of Cleveland, in the Smoke Prevention Division, engaged in the preparation of a preliminary report on the electrification of steam railroads in Cleveland. During the latter part of 1913 he was in the mechanical department of the Lake Shore and Michigan Southern Railroad.

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Mr. Francis Jehl, Mem. A. I. E. E., chief engineer of the General Electric Company of Budapest, Hungary, has been honored by Emperor Francis Joseph of Austria-Hungary with the Knight's Cross of the Francis Joseph Order. Mr. Jehl has been connected with the work of the Budapest General Electric Company for the past 17 years and has been prominently identified with electric lighting and power developments in Europe and America ever since the early development of the Edison incandescent electric lamp at Menlo Park, N. J., where he was one of Mr. Edison's earliest assistants. After wide experience in superintending electrical installations in Europe, Mr. Jehl had charge of the Edison exhibit at the Vienna Electrical Exhibition in 1883, during which he was presented at the Austrian Court. While in Vienna in 1899 he wrote the first complete work upon carbon manufacture, which was published in the London *Electrician*, and he took out a number of patents for inventions such as carbon economizers, a continuous furnace for carbon manufacture, an electric meter, and a Faraday disk type of dynamo, known as the Jehl-Ruppe disk dynamo. He has been a frequent contributor to the technical press both in this country and abroad.

## Obituary

Francis Wiley Jones, Member and past vice-president of the Institute, ex-assistant general manager of the Postal Telegraph-Cable Company, died of pneumonia at his winter home in West Palm Beach, Florida, on March 28, 1914, in his sixty-eighth year. Francis Wiley Jones was born in Weymouth, Nova Scotia. He learned telegraphy in 1859 while clerk in the post-office in Kentville, N. S. In 1867 he removed to St. John, New Brunswick, to accept a position as operator. Mr. Jones left St. John in 1872 for Chicago, where he accepted a position as night operator for the Western Union Telegraph Company. He was rapidly promoted, and became assistant electrician and assistant manager of the Chicago office. He was largely instrumental in the formation of the Chicago Electrical Society and the American Electrical Society. In 1874 he adapted the quadruplex system of sending messages, then just invented by Edison, to the work of the Western Union, and set up the first quadruplex west of New York. In the next year he greatly improved the system by changing it from the bridge to the differential form, and by applying condensers to mitigate the "kick." His modified quadruplex was soon in use all over the country. In 1879 he patented a device to obviate the inductive effects of electromagnets in telephone circuits. Mr. Jones was appointed in 1880 to the newly created position of general circuit manager of the Western Union Telegraph Company, with headquarters in New York, and while in this service he invented a sextuplex. In 1882 he resigned to become vice-president and general manager of the Union Electric Manufacturing Company, and improved many of the products of the company by his inventive ability. In 1884 he was appointed electrician of the Bankers' and Merchants' Telegraph Company, and in 1885 became general manager to the receiver of that company. Later he became assistant general manager and electrician of the joint United Lines and Postal Telegraph Company, and subsequently electrical engineer of the Postal Telegraph-Cable Company, with headquarters at New York. This position he retained until his retirement from active service in in 1907. Mr. Jones was a charter mem-

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ber of the American Institute of Electrical Engineers, and served as vice-president from 1885 to 1887. He was founder and first president of the New York Electrical Society, one time president of the Old Timers' Club, of the Magnetic Club, and member of the New York Telegraph Club and a life member of the New York Press Club.

## Abstracts of Proceedings of Foreign Engineering Societies

### Société Internationale des Electriciens

Meeting of February 4, 1914

"Dynamos for Automobile Lighting", by H. Armagnat.

The electric lighting of automobiles has undergone steady development since the time when it was decided to combine, on the car, storage batteries having the duty of furnishing energy at every moment, and a dynamo for recharging the batteries. What is of special interest for electrical engineers is the combination of means used to enable the dynamo, connected with a motor the speed of which may vary in the ratio of 1 to 6, to deliver the voltage at constant potential. The regulators (either proposed or used) make use of a mechanical phenomenon (centrifugal force), or of electromagnetic actions produced in special apparatus or in the dynamo itself.

Centrifugal force has served as a basis for several systems, providing for the regulation of the speed of the dynamo (slipping); providing for the cutting in of rheostats inserted in the field coils; or, finally, in providing a regulation of the length of the air-gap. Electromagnetic regulators maintain the voltage constant by acting on a field rheostat. To obtain a nearly constant voltage in the circuit, with the current flowing either to the lamps or into the storage batteries as the case may be, compounding of the field winding is often used, with the series circuit in opposition to the shunt circuit.

Numerous combinations have been proposed for utilizing the reaction of the field coils, either that which comes from the current generated, or by forming supplementary circuits the purpose of which is to intensify this reaction. A large number of regulators, from among the most modern types, involve an action on the field due to periodical interruptions of the excitation circuit; vibrating regulators are usually designed to maintain the electromotive force constant, but there are also such as maintain the current constant. Finally, some inventors propose to use alternators or machines with rectified current in which the increase of impedance with the increase of speed would compensate, to a certain extent, for the increase in electromotive force. These devices eliminate the use of storage batteries, and make it necessary to provide an auxiliary source of light to be used during stops.

An accessory apparatus, the use of which is, however, indispensable, viz., a circuit closing and breaking switch, is of great importance in all installations for lighting automobiles.

"New Apparatus, with Two Pointers, Instantaneous-Reading, for Measuring Resistance of Rail Joints", by Lebaupin.

All the present apparatus for measuring the resistance of rail joints require much time for use and give uncertain results. They require much time because the methods used require adjustments by trial, the results are uncertain because contact by simple pressure by hand is not sufficient. Further, they are nearly inapplicable on lines of mixed traffic (steam and electric). One may resort to indirect methods which give the average value of joints, but these are insufficient because, notwithstanding all precautions taken, a certain number of joints may happen to possess an excessive and inadmissible resistance.

It is owing to these considerations that the Eastern Railways have been forced to design a new apparatus free

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from the inconveniences of the previous ones, that is, giving direct readings, without trial adjustments. This new apparatus, provided with two pointers, has been constructed by Carpentier, in accordance with the principles of the Ferrié-Carpentier apparatus. It consists of two millivoltmeters the pointers of which cross in front of a dial on which is plotted a system of curves indicating length of rail in meters, in such a manner that the resistance of the joint is given directly in terms of meters of rail.

It is provided with two commutators permitting the operator to vary the sensitiveness of the apparatus. To prevent the apparatus from being injured when the current flowing in the rail happens to be too strong, or when a poor joint is encountered, the core and poles are made of special shape, so that the millivoltmeters have their maximum sensitiveness in the neighborhood of zero.

The junction box device is mechanically locked, and makes very good contacts possible. It takes its place automatically, and is removed likewise, without the slighest difficulty, so that the operator runs no danger whatsoever.

This new apparatus permits the instant comparison of joint resistances within one meter of rail. The speed of handling is nearly ten times as great as with the former types of apparatus. The last advantage of this apparatus is that, however unskilled the operator may be, he will, very rapidly and simply, obtain exact results. That is what cannot be done with other types of apparatus in which the readings have always to be approximated.

The instrument is further provided with a millivolt scale which permits the determination of the maximum and average loss of charge in the line.

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"A Contribution to the Study of Transformers", by P. Girault.

The author investigates no-load losses at constant effective voltage. The eddy current losses are substantially constant. The hysteresis losses depend only on the maximum value of the flux; the consideration of the form factor permits passing from the maximum flux to the average electromotive force. Calculation shows that maximum hysteresis loss is obtained with a triangular curve of flux, and minimum and zero values with rectangular flux of infinitely small height.

The author examines the question of excessive voltages and under-voltages and of oscillatory discharges, in connection with high-voltage tests. If one considers a combination of a self-inductance and capacity in series, energized under a difference of potential, of frequency $\omega$, and if this combination be short-circuited, in the particular case when the oscillation frequency is $\Omega > \omega$, one may obtain at the capacity terminals a factor of maximum excess of voltage $\gamma = 1$, and at the terminals of the self-inductance a factor of maximum excess of voltage $\lambda = \frac{\Omega^2}{\omega^2}$; this permits an explanation of the voltage surges between windings in a transformer flashing over to the core. These over-voltages may also be explained by sudden variations of voltage resulting from the discharges.

Resistances seem to be the best remedy against these oscillations. Excesses of current when the machine operates under a system of oscillations are easily explained. When horn gap lightning arresters are used, the resistance in series should be on the line side, and the horn gap on the ground side.

We know very little of the dielectrics, and use them in a barbarous manner, much worse than the way in which magnetic materials were used before the works of Hopkinson. For dielectrics we have not even anything corresponding to the Epstein apparatus.

Transformers operating in parallel: in all cases of operation in parallel, the vectors of the primary and secondary voltages are respectively in phase for the different apparatus; if the ratios of transformation at no-load are equal, the

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short-circuit hypothenuses are also equal.

The author states the operating conditions for various cases, deriving them either from the simplified Kapp diagram or from the consideration of the total coefficients of self and mutual induction. He closes by indicating some simple cases of phase adjustment and current distribution.

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## Library Accessions

The following accessions have been made to the Library of the Institute since the last acknowledgment.

American Institute of Electrical Engineers. Transactions vol. 31, pt. 1-2. New York, 1912. (Gift.)

American Telephone and Telegraph Company. Annual Report of the Directors 1913. New York, 1914. (Gift of American Telephone and Telegraph Company.)

Annales de Chimie et de Physique, Table des noms d'auteurs et table analytique des matieres. Ser. 6, vols. 1-30, 1884-1893. Paris, 1895. (Purchase.)

Association Suisse des Electriciens et Union des Centrales Suisses D'Electricite. Statistique des installations electriques a courant fort. Stations centrales Categorie A. Annee 1911. Zurich, 1913. (Purchase.)

Associazione Elettrotecnica Italiana. Atti vol. 10, 1906. Milano, 1906. (Purchase.)

Carnegie Institution of Washington. Annual Report of the Director of the Department of Terrestrial Magnetism 1912-1913. Washington, N.d. (Gift of Carnegie Institution of Washington.)

Contributo allo studio della tarifficazione dell'-energia elettrica. By Renzo Norsa. Milano, n.d. (Gift of author.)

Economics of Interurban Railways. By L. E. Fischer. New York, 1914. (Purchase.)

Electric Car Maintenance. By Walter Jackson. New York, 1914. (Purchase.)

Electrical Trades' Directory and Handbook for 1914. London, 1914. (Purchase.)

Elektrochemische Zeitschrift. vol. I, nos. 2-12; vols. 2-5; vol. 6, nos. 1-9. Berlin, 1894-1899. (Purchase.)

Die Fabrikation und Eigenschaften der Metalldrahtlampen. By N. L. Muller. Halle a.S., Wilhelm Knapp, 1914. (Gift of Publishers.) Price 8.60 Mks.

More than half of this work is given up to the manufacture of metal filament lamps, the remainder being devoted to the behavior when in use. W. P. C.

Government Ownership of Electrical Means of Communication. Washington, 1914. Gift of U. S. Senate.)

Inspector and the Insured. An address delivered before the 94th Meeting of the Insurance Society of New York, Feb. 24, 1914. By F. M. Griswold. (Gift of Insurance Society of New York.)

Jahrbuch der Elektrotechnik. 1 Jahrgang, 1912. By Karl Strecker. München-Berlin, 1913. (Purchase.)

Light, Radiation and Illumination. Translated from the German of Paul Hogner by Justus Eck. London, n.d. (Purchase.)

La Lumière Electrique et ses différentes applications au Théatre. By V. Trudelle. Paris, 1914. (Purchase.)

Missouri. Public Service Commission. McGregor-Noe Hardware Company, *et. al.* vs. Springfield Gas and Electric Company and Springfield Traction Company. Brief and Argument on Behalf of Defendants. N.P. n.d. (Gift of Sanderson and Porter.)

National Association of Railway Commissioners. Proceedings of the 25th Annual Convention, 1913. New York, Law Reporting Co., n.d. (Gift of publishers.) Price $1.00.

The publications of this Association are of great interest to the officers of public service corporations. The subjects discussed are such as are prominent in the economic discussions of the day. W. P. C.

La Protection des Réseaux et des Installations électriques contre les surtensions. By G. Capart. Paris, 1914. (Purchase.)

Royal Society of London. Philosophical Transactions. Ser. A—vol. 213. London, 1914. (Gift of Adams Fund.)

Society of Chemical Industry. List of Members 1914. London, 1914. (Gift of Society of Chemical Industry.)

State and the Insurance Company. An address delivered before the 96th Meeting of the Insurance Society of New York, March 24, 1914. By David Rumsey. n.p. n.d. (Gift of Insurance Society of New York.)

Les Surtensions dans les distributions d'énergie electrique et les Moyens d'en prevenir les Inconvénients. By I. Van Dam. Paris, 1913. (Gift of Gauthier-Villars.)

This treatment of high-tension transmission is designed to summarize American practise in protection of transmission lines, for the use of those contemplating the establishment of high-tension plants in Europe. The author is connected with the Technical Department of the telegraphic service in the Netherlands. W. P. C.

Travaux du Laboratoire Central D'Electricité. By P. Janet (Société Internationale des Electriciens. Tome III) Paris, 1914. (Gift of Gauthier-Villars.)

The third volume of this series of papers contains articles on the physiological effect of the electric current; electrocution experiments; magnetic-measurements; cloth insulation; study of new electric lamps, measurement of wave length in wireless telegraphy, and several other subjects. W. P. C.

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| **Portland, Ore**.....May 18, '09 | G. P. Nock. | R. F. Monges, G. E. Co., Electric Building, Portland, Ore. |
| **St. Louis**.....Jan. 14, '03 | F. J. Bullivant. | A. McR. Harrelson, Emerson Electric Mfg. Co., St. Louis, Mo. |
| **San Francisco**...Dec. 23, '04 | A. H. Griswold. | A. G. Jones, 819 Rialto Building, San Francisco, Cal. |
| **Schenectady**.....Jan. 26, '03 | George H. Hill. | John R. Hewett, Gen. Elec. Co., Schenectady, N. Y. |
| **Seattle**.....Jan. 19, '04 | S. C. Lindsay. | E. A. Loew, University of Washington, Seattle, Wash. |
| **Spokane**.....Feb. 14, '13 | J. B. Fisken. | H. B. Peirce, Box 1436, Spokane, Wash. |
| **Toledo**.....June 3, '07 | George E. Kirk. | Max Neuber, Cohen, Freidlander & Martin, Toledo, O. |
| **Toronto**.....Sept. 30, '03 | D. H. McDougall. | H. T. Case, Continental Life Bldg., Toronto, Ont. |
| **Urbana**.....Nov. 25, '02 | Morgan Brooks. | I. W. Fisk, University of Illinois, Urbana, Ill. |
| **Vancouver**.....Aug. 22, '11 | E. M. Breed. | L. G. Robinson, 1003 Holden Building, Vancouver, B. C. |
| **Washington, D.C.**.Apr. 9, '03 | H. C. Eddy. | C. B. Mirick, 1330 New York Avenue, N.W., Washington, D.C. |

**Total, 30.**

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# LIST OF BRANCHES

Revised to May 1, 1914.

| Name and when Organized. | Chairman | Secretary |
|---|---|---|
| **Agricultural and Mechanical College of Texas**.....Nov. 12, '09 | D. B. Pickens. | E. C. Rack, A. & M. College, College Station, Tex. |
| **Arkansas, Univ. of**.....Mar. 25, '04 | S. S. McGill. | M. B. Roys, Univ. of Arkansas, Fayetteville, Ark. |
| **Armour Institute**.....Feb. 26, '04 | E. L. Nelson. | T. C. Bolton, Armour Inst. Tech., Chicago, Ill. |
| **Bucknell University**.....May 17,'10 | F. O. Schnure. | J. M. Hillman, Bucknell University, Lewisburg, Pa. |
| **California, Univ. of**.....Feb. 9, '12 | Charles Z. Yost. | L. E. Rushton, University of California, Berkeley, Cal. |
| **Cincinnati, Univ. of**.....Apr. 10, '08 | John H. Stewart. | J. S. Bishop. 2345 Kemper Lane, Cincinnati, Ohio. |
| **Clemson Agricultural College**.....Nov. 8, '12 | F. J. Jervey. | F. H. McDonald, Clemson College, S. C. |
| **Colorado State Agricultural College**.....Feb. 11, '10 | L. M. Klinefelter. | R. K. Havighorst. Colorado State Agricultural College, Fort Collins, Colo. |
| **Colorado, Univ. of**.....Dec. 16, 04 | L. E. Sweitzer. | Frank A. Redding, University of Colorado, Boulder, Colo. |
| **Highland Park College**..Oct. 11, '12 | E. B. Williams, | Ralph R. Chatterton, Highland Park College, Des Moines, Iowa. |
| **Iowa State College**.....Apr. 15, '03 | Earle G. Nichols. | F. A. Robbins, Iowa State College, Ames, Iowa. |
| **Iowa, Univ. of**.....May. 18, '09 | J. H. Scanlon. | A. H. Ford, University of Iowa, Iowa City, Ia. |
| **Kansas State Agr. Col.**..Jan. 10, '08 | L. O'Brien. | W. C. Lane, Kansas State Agric. Col., Manhattan, Kan. |
| **Kansas, Univ. of**.....Mar. 18, '08 | H. C. Hansen. | L. M. Bocker, Univ. of Kansas, Lawrence, Kansas. |
| **Kentucky State Univ. of**.Oct. 14, '10 | H. B. Hedges. | H. Tyler Watts, 315 East Maxwell Street, Lexington, Ky. |
| **Lafayette College**.....Apr. 5, '12 | G. P. Ellis. | V. A. Davison, Lafayette College, Easton, Pa. |
| **Lehigh University**.....Oct. 15, '02 | W. B. Todd. | G. Forster, Lehigh University, S. Bethlehem, Pa. |
| **Lewis Institute**.....Nov. 8, '07 | A. H. Pensholt, | Fred A. Rogers, Lewis Institute, Chicago, Ill. |
| **Maine, Univ. of**.....Dec. 26, '06 | C. M. Kelley. | E. L. Getchell, University of Maine, Orono, Maine. |
| **Michigan, Univ. of**.....Mar. 25, '04 | P. H. Evans. | E. T. Anderson, 608 Mary Court, Ann Arbor, Mich. |
| **Missouri, Univ. of**.....Jan. 10, '03 | H. B. Shaw. | E. W. Kellogg, 9 Engineering Building, Columbia, Mo. |
| **Montana State Col.**.....May 21, '07 | Max W. Kenck. | J. A. Thaler, Montana State College, Bozeman, Mont. |

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## LIST OF BRANCHES—Continued

| Name and when Organized | Chairman | Secretary |
|---|---|---|
| Nebraska, Univ. of.....Apr. 10, '08 | Olin J. Ferguson. | V. L. Hollister, Station A, Lincoln, Nebraska |
| New Hampshire Col.....Feb. 19, '09 | | |
| North Carolina Col. of Agr. and Mech. Arts.....Feb. 11, '10 | Wm.H.Browne,Jr. | James Fontaine, West Raleigh, N. C. |
| Ohio Northern Univ.....Feb. 9, '12 | George E. Boesger | Harry Restofski, Ohio Northern University, Ada, Ohio. |
| Ohio State Univ.....Dec. 20, '02 | L. R. Yeager. | John M. Strait, Ohio State Univ., Columbus, Ohio. |
| Oklahoma Agricultural and Mech. Col.....Oct. 13, '11 | A. P. Little. | Quentin Graham, 118 Husband St., Stillwater, Okla. |
| Oklahoma, Univ. of.....Oct. 11, '12 | R. D. Evans. | L. J. Hibbard, Univ. of Oklahoma, Norman, Okla. |
| Oregon Agr. Col.....Mar. 24, '08 | A. O. Manigold. | I. L. Olmstead, Oregon Agric. Col., Corvallis, Ore. |
| Oregon, Univ. of.....Nov. 11, '10 | C. R. Reid. | C. H. Van Duyn, Univ. of Oregon, Eugene, Oregon. |
| Penn State College.....Dec. 20, '02 | A. D. Shultz, | A. T. McNeile, State College, Pa. |
| Pittsburgh, University of.Feb. 26, '14 | | |
| Purdue Univ.....Jan. 26, '03 | C. F. Harding. | A. N. Topping, Purdue University, Lafayette, Ind. |
| Rensselaer Poly. Inst....Nov. 12, '09 | W. J. Williams, | H. F. Wilson Rensselaer Poly. Institute, Troy, N. Y. |
| Rose Polytechnic Inst....Nov. 10, '11 | Charles F. Harris. | Claude A. Lyon, 1331 Liberty Avenue, Terre Haute, Ind. |
| Rhode Island State Col..Mar. 14, '13 | Harry Webb. | P. M. Randall, Rhode Island State College, Kingston, R. I. |
| Stanford Univ.....Dec. 13, '07 | G. O. Wilson. | L. M. Bussert, Stanford University, Cal. |
| Syracuse Univ.....Feb. 24, '05 | W. P. Graham. | R. A. Porter, Syracuse University, Syracuse, N. Y. |
| Texas, Univ. of.....Feb. 14, '08 | Joseph W.Ramsey, | J. A. Correll. University of Texas, Austin, Tex. |
| Throop College of Technology.....Oct. 14, '10 | W. L. Newton, | A. W. Wells, Throop Poly. Institute, Pasadena, Cal. |
| Vermont, Univ. of.....Nov. 11, '10 | | |
| Virginia, Univ. of.....Feb. 9, '12 | Walter S. Rodman | H. Anderson, Jr., 1022 West Main St., Charlottesville, Va. |
| Wash., State Col. of....Dec. 13, '07 | M. K. Akers. | H. V. Carpenter, State Coll. of Wash., Pullman, Wash. |
| Washington Univ.....Feb. 6, '04 | R. D. Duncan, Jr. | C. C. Hardy, Washington University, St. Louis, Mo. |
| Washington, Univ. of...Dec. 13, '12 | A. P. Newbury. | Charles A. Stanwick, Univ. of Washington, Seattle, Wash. |
| Worcester Poly. Inst.....Mar. 25, '04 | W. C. Blanchard. | Harry B. Lindsay, Worcester Poly. Inst., Worcester, Mass. |
| Yale University.....Oct. 03, 10 | R. G. Warner. | K. B. Jones, 70 Trumbull St., New Haven, Conn. |

Total, 48.

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# SECTION II

# PROCEEDINGS

of the

# American Institute

of

# Electrical Engineers

## Papers, Discussions and Reports

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# PROCEEDINGS

OF THE

## American Institute

OF

## Electrical Engineers.

Published monthly by the A. I. E. E., at 33 W. 39th St., New York, under the supervision of

THE EDITING COMMITTEE

GEORGE R. METCALFE, Editor

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Vol. XXXIII **June, 1914** No. 6


### The Detroit Convention

The Thirty-First Annual Convention of the American Institute of Electrical Engineers will be held in Detroit, Michigan, June 22 to 26, 1914. The convention headquarters of the Institute will be at the Hotel Pontchartrain, where the technical sessions will be held. Members are requested to register at Institute headquarters on their arrival at Detroit. The following program has been arranged:

### PROGRAM

#### Monday, June 22

9:00 P.M.

Reception and dance.

#### Tuesday, June 23

10:00 A.M.

President's Address, by C. O. Mailloux.

10:45 A.M.

*Committee on Electricity in Marine Work:*

1. *Electric Heating as Applied to Marine Service*, by C. S. McDowell and D. M. Mahood.
2. *The Electrically Driven Gyroscope in Marine Work*, by H. C. Ford.

12:30 to 2:30 P.M.

Section Delegates' luncheon.

2:30 P.M.

Automobile trip.

8:15 P.M.

*Industrial Power Committee:*

3. *Direct-Current Motors for Coal and Ore Bridges*, by R. H. McLain.
4. *Method of Keeping Down Peaks on Power Purchased on a Peak Basis*, by T. E. Tynes.
5. *Concatenated Induction Motors for Rolling Mill Drive*, by William Oschmann.

Moving pictures, illustrating operation of tube mills, from ore to finished pipe.

8:30 P.M.

Ladies' card party.

#### Wednesday, June 24

10:00 A.M.

*Electrophysics Committee:*

6. *The Sphere Gap as a Means of Measuring High Voltage*, by F. W. Peek, Jr.
7. *The Electric Strength of Air—V*, by J. B. Whitehead and W. S. Gorton.
8. *Sphere-Gap Discharge Voltages at High Frequencies*, by J. C. Clark and H. J. Ryan.

12:30 to 2:30 P.M.

Section Delegates' luncheon.

2:30 P.M.

Boat trip, sports, etc., and supper on Bois Blanc Island.

EVENING

Boat trip returning from Bois Blanc Island.

#### Thursday, June 25

10:00 A.M.

*Engineering Data Committee:*

9. *Data on High-Tension Transmission Systems*, by Percy H. Thomas.
10. *Specification for Inspection and Tests of High-Tension Line Insulators*, Committee Report.

12:30 to 2:30 P.M.

Section Delegates' luncheon.

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2:30 P.M.

*Prime Movers Committee:*

11. *Present Status of Prime Movers*, by H. G. Stott, W. S. Gorsuch, and R. J. S. Pigott.

*Cable Testing:*

12. *Voltage Testing of Cables*, by W. I. Middleton and Chester L. Dawes.

Ladies' putting contest.

8:15 P.M.

Presentation of Edison Medal and Past-Presidents' Badges.

Introduction of President-elect Paul M. Lincoln.

9:30 P.M.

Dancing and private cabaret.

**Friday, June 26**

9:00 A.M.

Board of Directors' meeting.

10:00 A.M.

*Electrochemical Committee:*

13. *Sterilization of Water by Ultra-Violet Rays*, by M. von Recklinghausen.

*Telegraphy and Telephony Committee:*

14. *Toll Telephone Traffic*, by Frank F. Fowle.
15. *A High-Speed Printing Telegraph System*, by Carl Kinsley.

12:30 to 2:30 P.M.

Section Delegates' luncheon.

2:30 P.M.

Conference of Section Delegates and Officers. All members welcome.

**Entertainment**

Tentative arrangements have been made for the following social features:

Monday evening, June 22: Reception and dance at the Hotel Pontchartrain, to which all members and their guests are invited.

Tuesday afternoon, June 23: Sightseeing automobile trip.

Tuesday afternoon, June 23: Tennis and golf tournaments.

Tuesday evening, June 23: Ladies' card party.

Wednesday afternoon, June 24: Steamboat trip; sports and supper on Bois Blanc Island.

Thursday afternoon, June 25: Ladies' putting contest.

Thursday evening, June 25: Dancing and private cabaret.

The elimination rounds of golf and tennis will begin on Tuesday afternoon, and therefore entries for the contests should be made, with the committees in charge, as early as possible.

Arrangements have been made to have the golf contest at the Detroit Golf Club, but golf privileges will possibly be available also at the Bloomfield Hills Country Club.

Those entering the golf contest may have the opportunity of competing for the Mershon golf trophy, a very handsome silver cup contributed by Past-President Mershon at the Cooperstown Convention in 1913. The cup is to be finally awarded to the person winning the golf championship twice at Institute Annual Conventions.

The tennis elimination matches will probably be played at the Detroit Tennis Club, with the finals at the Detroit Golf Club.

Automobiles will be available for members and their guests for shopping tours and trips about town without charge at all times.

Arrangements will be made for dancing every evening during the convention.

**Hotel Arrangements**

The Convention Committee has reserved tentatively 150 rooms at the Hotel Pontchartrain, where the Institute will make its headquarters. Each member should make his own reservations, by communicating directly with the hotel, as early as possible. Failure to make prompt reservations may result in disappointment. It should also be noted that the Hotel Pontchartrain is operated on the European plan. The rates for rooms are as follows:

Single rooms, running water, $2.00-$2.50 per day.

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Single rooms, with bath, $3.00-$3.50-$4.00-$5.00 per day.

Double rooms, running water, $3.00-$4.00 per day.

Double rooms, with bath, $5.00-$6.00-$7.00-$8.00 per day.

Suites $8.00-$10.00-$12.00-$15.00 per day.

### Registration

Each member and guest will receive upon registration a badge bearing his or her name, to be worn during the convention for the purpose of identification. Registration headquarters will be at the Hotel Pontchartrain, and it will greatly facilitate matters if members and their guests will register immediately upon arrival.

### Transportation

No special transportation rates are available, and members should consult their local ticket agents regarding routes and rates. Parlor and sleeping car accommodations should be engaged in advance.

### Detroit—The Convention City

The city of Detroit, which has been selected for the 1914 A. I. E. E. Annual Convention, is essentially a convention city, as statistics show that an average of 150 conventions of national and international organizations are held in Detroit each year. Of the million or more annual visitors to Detroit, about one-half go there to attend conventions, so that making visitors welcome is one of the regular occupations of Detroiters.

It is believed that the selection of Detroit for this year's convention will result in a record attendance, as the location of the city is very central and it is easily accessible by railroad to a large part of the membership residing in eastern as well as the central western states. Detroit is the metropolis of Michigan and has a population exceeding 500,000. It is the seventh city in size in the United States, and is generally considered one of the most beautiful cities in the country. It is well known as the center of the automobile industry of the world, and its manufacturing and industrial interests are very large and are steadily increasing.

The natural attractions of Detroit make it of special interest to visitors. Situated on the Detroit River with its numerous and picturesque islands, boat rides to numerous pleasure resorts have become one of the principal summer pastimes at Detroit. One of these resorts is Bois Blanc Island, located 19 miles from the city, at the junction of the Detroit River with Lake Erie. On this island, which is locally named "Bob-Lo", the Institute's "outing day" will be spent. Another popular resort is Belle Island, a beautiful island park situated 2½ miles from the center of the city in the middle of the river at the junction with Lake St. Clair. Other boat trips, too numerous to mention in detail, reach many points of interest along the river and lakes and several Canadian cities.

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## Pacific Coast Convention, Spokane, Wash., September 9-11, 1914

The sixth annual Pacific Coast Convention of the A. I. E. E. will be held this year in Spokane, Wash., on September 9, 10 and 11, under the auspices of the Spokane Section of the Institute. The arrangements for it are being made by the special Convention Committee, the personnel of which was announced in the May issue of the PROCEEDINGS.

Institute headquarters during the meeting will be at the new Davenport Hotel, and the sessions will be held there.

The Transportation Committee has made arrangements with the railways for reduced rates (fare and one-third) from all points in California, Nevada, Oregon, Washington, Idaho, Montana, Wyoming, Utah, Colorado and British Columbia. From other points the tourist reduced rates will be in effect.

The Entertainment Committee is planning for the visiting ladies a reception, a theater party and automobile

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trips around Spokane and to points of interest in the vicinity. On one of the evenings there will be given an illustrated talk on the International Electrical Congress and the Panama-Pacific Exposition, San Francisco, 1915. This will be combined with some music and will be for the ladies as well as the men. Arrangements are being made for interesting trips to hydroelectric generating stations, under construction and in operation, in the vicinity of Spokane, and to some of the typical substations.

Further announcements of the details of the convention program and the titles of papers to be presented will be given in succeeding issues of the PROCEEDINGS.

## Report of Committe of Tellers on Election of Officers

*To the President,*
*American Institute of Electrical Engineers.*

DEAR SIR:—This committee has carefully canvassed the ballots cats for officers for the year 1914-1915. The result is as follows:

| | | |
|---|---|---|
| Total number of ballot envelopes received | | 2529 |
| Rejected on account of bearing no identifying name on outer envelope, according to Article VI, Section 33, of the Constitution | 25 | |
| Rejected on account of voter being in arrears for dues on May 1, 1914, as provided in the Constitution and By-Laws | 79 | |
| Rejected on account of ballot not being enclosed in inner envelope, or on account of inner envelope bearing an identifying name, according to Article VI, Section 33, of the Constitution | 51 | |
| Rejected on account of having reached the Secretary's office after May 1, according to Article VI, Section 33 of the Constitution | 18 | 173 |
| Leaving as valid ballots | | 2356 |

These 2356 valid ballots were counted and the result is shown as follows:

*For President*

| | |
|---|---|
| P. M. Lincoln | 2351 |
| Scattering and blank | 5 |

*For Vice-Presidents*

| | |
|---|---|
| F. S. Hunting | 2343 |
| N. W. Storer | 2343 |
| Farley Osgood | 2338 |
| Scattering and blank | 44 |

*For Managers*

| | |
|---|---|
| Frederick Bedell | 2324 |
| B. Gherardi | 2234 |
| J. H. Finney | 2234 |
| A. S. McAllister | 2170 |
| E. J. Berg | 305 |
| Scattering and blank | 157 |

*For Treasurer*

| | |
|---|---|
| George A. Hamilton | 2355 |
| Scattering and blank | 1 |

Respectfully submitted,
J. H. PAYNE, *chairman*,
S. D. KUTNER.
ROGER MASON.
R. W. STAFFORD.
C. F. THOMPSON.
May 11, 1914. *Committee of Tellers*

## Directors' Meeting, New York, May 19, 1914

The Board of Directors of the Institute held its regular monthly meeting in New York on Tuesday, May 19, at 3:30 p.m.

There were present; President C. O. Mailloux, New York; Past-President Gano Dunn, New York; Vice-Presidents S. D. Sprong and H. H. Barnes, Jr., New York; Managers N. W. Storer, Pittsburgh, Pa., Farley Osgood, Newark, N. J., C. A. Adams, Cambridge, Mass., J. Franklin Stevens, Philadelphia, Pa., William McClellan, New York; Treasurer George A. Hamilton, Elizabeth, N. J., and Secretary F. L. Hutchinson, New York.

The action of the Finance Committee in approving monthly bills amounting to $11,038.35 was ratified.

The annual reports of the Finance Committee, and of the Treasurer, for the year ending April 30, 1914, were presented and accepted.

Upon the recommendation of the Board of Examiners, the Board of Directors transferred one member of the Institute to the grade of Fellow and four to the grade of Member, elect-

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ed two applicants as Members and 54 as Associates, and ordered the enrolment of 98 students, in accordance with the lists printed in this issue of the PROCEEDINGS.

Upon the petition of the Portland Section, and the approval of the Sections and Finance Committees, the territory of that Section was extended to include the following: Corvallis, Eugene, The Dalles, Astoria, and Tillamook, Oregon, and Winlock, Washington.

Mr. F. L. Hutchinson was unanimously reappointed Secretary of the Institute for the coming administrative year, beginning August 1, 1914.

The Annual Report of the Board of Directors, containing a summary of the work accomplished during the fiscal year ending April 30, 1914, together with statements showing the status of the Institute's financial affairs, was approved. This report was presented at the Annual Meeting of the Institute in the evening, and is printed in this issue of the PROCEEDINGS.

The annual reports of committees for the same period, abstracts of which are incorporated in the directors' annual report, were presented and accepted, and the Secretary was instructed to transmit to the succeeding committees, when appointed, such recommendations as may be embodied therein.

A communication was presented from the Library Board of the United Engineering Society requesting the appointment of a representative of the Institute upon a joint committee to consider the question of duplication of the exchange of publications and the possibility of retrenchment in the expenses incurred by these duplications.

The President was authorized to appoint this representative.

A communication was presented from the Board of Trustees of the United Engineering Society informing the Board of the receipt of a gift from Mr. John W. Lieb of a series of volumes covering the life and work of Leonardo da Vinci, and expressing the hope that Mr. Lieb's gift might lead to other donations of a like nature.

The Board directed the Secretary to express to Mr. Lieb its appreciation of his gift to the United Engineering Society.

An invitation was presented from Cooper Union, New York, to appoint a representative of the Institute to attend the Cooper Union commencement exercises on May 29, at which a tablet to the memory of Professor William A. Anthony, past-president of the Institute, was to be dedicated.

The matter was referred to President Mailloux with power, and he subsequently appointed Past-President John W. Lieb to represent the Institute.

## Specification and Agreement for Joint Use of Poles

The American Electric Railway Association appointed a joint committee including representatives of the A. I. E. E., the N. E. L. A. and the A. T. & T. Company to prepare a specification to cover the joint use of poles by electric light, electric railway, telephone and other interests and to draw up an agreement suitable for such joint use. After two years' work a draft of specification and agreement has been prepared by the Joint Committee and is now offered for criticism by engineers or companies who may be interested in the subject. Members of the A. I. E. E. may obtain copies of this specification and agreement by application to the Secretary. All criticisms should be returned to Mr. W. J. Harvie, Chairman, American Electric Railway Association, 33 West 39th Street, New York, by July 1, 1914.

## Valuable Gift to Library

A valuable accession to the joint library of the engineering societies, and one which will be appreciated by those interested in its progressive upbuilding, was recently presented to the Board of Trustees of the United Engineering Society by Mr. John W. Lieb. This

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gift consists of a series of 12 volumes relating to the life and work of the distinguished Italian scientist, philosopher, and artist, Leonardo da Vinci. Six of the volumes, published under the auspices of the Italian Government in Milan in 1894, are reproduced from the well-known Codice Atlantico of da Vinci. The remaining six include da Vinci's notebooks, rendered into English, and a number of miscellaneous and interesting monographs in French and German, dealing with various phases of the great Italian's work. It is the hope of the Board of Trustees of the United Engineering Society, and also of the Board of Directors of the Institute, that Mr. Lieb's generous action may stimulate further donations of like nature, and that this collection may form the basis of a department comprising the history of the mechanic arts in this and other countries, with biographies and other literature of great men who have labored in this field.

## Testimonial to Mr. Herman Aaron, General Counsel of the Institute

At a recent meeting of the Board of Directors of the Institute, a special committee which had been appointed by the Board to consider the question of suitably expressing to Mr. Herman Aaron the Institute's appreciation of the services rendered by him gratuitously during the ten years he has acted as its legal counsel, submitted for the Board's consideration the following resolution embodying its recommendations:

*Whereas*, March the 25th, 1914, is the 10th anniversary of the appointment of Messrs. Parker and Aaron as General Counsel of the Institute, and

*Whereas*, the Institute is greatly indebted to Mr. Herman Aaron, as counsel, for his frequent, vital and wholly successful professional services throughout this period, for which he has refused all emolument,

*Resolved*, that the appreciation of the Institute be expressed to Mr. Aaron by the gift of a silver service to be presented, with appropriate formalities, on or about March the 25th, 1914.

This resolution was unanimously adopted, and a committee consisting of Messrs. John J. Carty, chairman, C. E. Scribner, and S. D. Sprong, was appointed to carry out the intent of the resolution.

This committee arranged for the presentation of the silver service, consisting of eight pieces of a simple and attractive Colonial design, by Tiffany and Company, at an informal dinner at the Engineers' Club, New York, Tuesday evening, May 19, which was attended by members of the Board of Directors, the committee, and a few personal friends of Mr. Aaron. President Mailloux presided, and the presentation address was made by Mr. Carty, who is entitled to the credit of obtaining the services of Mr. Aaron ten years ago, at which time Mr. Carty was chairman of the Finance Committee and a member of the Board of Directors. Mr. Carty spoke feelingly of the valuable services rendered by Mr. Aaron at the time negotiations were being carried on relative to the proposed gift by Mr. Carnegie, to the engineering profession, of a suitable building as a home for the principal national engineering societies, and paid a high tribute to the public service rendered by Mr. Aaron at that time, and also as general counsel of the Institute during the entire last decade. After an appropriate response by Mr. Aaron, all present expressed in brief addresses their high opinion of the able, loyal, and exceedingly efficient services rendered by Mr. Aaron to the Institute.

## Joint Meeting in Washington, D. C., April 24-25, 1914

The 294th meeting of the A. I. E. E. was a joint meeting with the American Physical Society, held in Washington, D. C., Friday and Saturday, April 24 and 25, 1914. The Institute's part of the program was arranged and conducted by the Electrophysics Committee and the Washington and Baltimore Sections. Five papers were presented on behalf of the A. I. E. E., in accordance with the program published in the

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April PROCEEDINGS, and fifty papers were presented by members of the American Physical Society. Most of these papers were briefly abstracted by their authors.

The sessions were held in the new electrical laboratory of the Bureau of Standards, which was thrown open so that the visitors might inspect its equipment of instruments and apparatus. On the afternoon of April 24 there was a demonstration of laboratory methods in the Bureau of Standards, and an exhibition, under the auspices of the American Physical Society, of recently developed laboratory, lecture, and research apparatus supplied by manufacturers, dealers, federal government departments, universities, and private individuals.

The five A. I. E. E. papers were presented at the session of Friday evening, which was followed by a smoker. On Saturday afternoon parties of those attending the meeting visited various points of interest in Washington, under the guidance of members of the Washington Section of the A. I. E. E.

An interesting feature of the meeting was an address by Sir Ernest Rutherford, F.R.S., on "X-Ray and Gamma-Ray Spectra," describing some of his experiments in spectrum analysis, using some of these extremely short wavelengths.

## A. I. E. E. Annual Meeting in New York, May 19, 1914

The Annual Meeting of the Institute (295th meeting) was held on May 19, 1914, in the auditorium of the Engineering Societies Building, New York.

President C. O. Mailloux called the meeting to order at 8:40 p.m., and asked Secretary F. L. Hutchinson to present the report of the Board of Directors for the fiscal year ending April 30, 1914. Printed copies of the report, which appears in Section II of this issue, had been distributed at the meeting, so Secretary Hutchinson merely outlined some of the principal points, stating that the Secretary's office would be glad at any time to answer inquiries of members in regard to any features of the Institute's work or finances. On motion, duly made and seconded, the report was adopted and ordered printed in the PROCEEDINGS and TRANSACTIONS.

President Mailloux then called upon Mr. J. H. Payne to present the report of the Committee of Tellers on Election of Officers. (This report is printed in Section I of this issue.) The president thereupon announced the election of the following officers, to assume office at the beginning of the administrative year, August 1, 1914: President, Mr. Paul M. Lincoln, Pittsburgh, Pa.; Vice-Presidents, Messrs. F. S. Hunting, Fort Wayne, Ind., Farley Osgood, Newark, N. J., and N. W. Storer, Pittsburgh, Pa.; Managers, Messrs. Frederick Bedell, Ithaca, N. Y., J. H. Finney, Washington, D. C., Bancroft Gherardi, New York, and A. S. McAllister, New York; Treasurer, Mr. George A. Hamilton, Elizabeth, N. J.

The annual business meeting having been concluded, President Mailloux invited Lieut. C. S. McDowell, U.S.N., chairman of the Committee on Use of Electricity in Marine Work, to preside during the presentation and discussion of the two technical papers.

Mr. H. L. Hibbard first presented his paper, entitled *Electricity the Future Power for Steering Vessels*. Chairman McDowell invited all members of the Society of Naval Architects and Marine Engineers and the American Society of Naval Engineers who were present to participate in the discussion. Mr. Hibbard's paper was discussed by Messrs. G. A. Pierce, Jr., Mathias Pfatischer, Maxwell W. Day, R. A. Beekman and H. L. Hibbard.

Mr. H. J. Mauger then presented his paper on *The Future of Electric Heating and Cooking in Marine Service*. This was discussed by Messrs. W. S. Hadaway, E. F. Dutton and H. J. Mauger.

At the close of the discussion the meeting was adjourned for the social re-

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union and smoker in the Institute's rooms on the 10th floor. This was the last New York smoker of the season.

## Addresses Wanted

| Name | Former address. |
|---|---|
| Oscar Elmore, | 121 Rose Lawn Drive, Los Angeles, Cal. |
| A. R. Harris, | Edison Storage Battery Co., Orange, N. J. |
| J. F. Hodgson, | 793 Westminster Road, Brooklyn, N. Y. |
| M. G. Rees, | 1428 N. Y. Life Bldg., Chicago, Ill. |

Anyone who can give information that may assist in obtaining any of these addresses is requested to communicate with the Secretary of the Institute.

## Recommended for Transfer, May 14, 1914

The Board of Examiners, at its regular monthly meeting on May 14, 1914, recommended the following members of the Institute for transfer to the grades of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

### To the Grade of Fellow

DAMON, GEORGE A., Consulting Engineer, Los Angeles, Cal., Dean, Throop College of Technology, Pasadena, Cal.

KETTERING, CHARLES FRANKLIN, Vice-President & General Manager, Dayton Engineering Laboratories Co., Dayton, O.

MULLER, HENRY N., Supt. of Distribution, Duquesne Lt. Co., Pittsburgh, Pa.

WOOD, HARRY P., Professor of Electrical Engineering, Georgia School of Technology, Atlanta, Ga.

### To the Grade of Member

ALEXANDER, MAGNUS W., General Electric Co., West Lynn, Mass.

ALLAN, WILLIAM G., Designing Electrical Engineer, Toronto Power Co., Ltd., Niagara Falls, Ont.

ALLNER, FREDERICK A., General Supt., Pennsylvania Water & Power Co., Baltimore, Md.

CARY, WALTER, Vice-President and General Manager, Westinghouse Lamp Co., New York N. Y.

CLAYTOR, WILLIAM G., Supt. Light & Power Dept., Roanoke & Electric Railway Co., Roanoke City, Va.

CUNNINGHAM, EDWARD ROBERT, Electrical Engineer, Oregon Electric & United Railways, Portland, Ore.

DEL MAR, WILLIAM A., Technical Assistant, Elec. Dept., N. Y. C. & H. R. R. R. Co., New York, N. Y.

FRANK, KARL GEORG, Representative, Siemens & Halske A. G., & Siemens-Schuckert Werke G. m. b. H., Berlin, Germany.

JONES, HAMILTON MCRARY, Supt., Lighting Division, Porto Rico Railway & Power Co., Consulting Electrical Engineer, Government P. R. Irrigation Service, San Juan, P. R.

PARKER, RALZEMOND DRAKE, Engineer, American Telephone & Telegraph Co., New York, N. Y.

SNOW, JOHN EDWIN, Professor of Electrical Engineering, Armour Institute of Technology, Chicago, Ill.

## Transferred to the Grade of Fellow May 19, 1914

The following Member was transferred to the grade of Fellow of the Institute at the meeting of the Board of Directors on May 19, 1914.

FECHHEIMER, CARL J., Crocker-Wheeler Co., Ampere, N. J.

## Transferred to the Grade of Member May 19, 1914

The following Associates were transferred to the grade of Member of the Institute at the meeting of the Board of Directors on May 19, 1914.

BOWLING, VICTOR S., Electrical Engineering and Contracting; President, Shearer Electrical Construction Co., Mexico City, Mexico.

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BUTTERS, J. H., Engineer in chief, Hydro-Electric Power & Metallurgical Co. Ltd., Hobart, Tasmania.

CORNELIUS, MARTIN, Electrical Engineer, Switchboard Div., Engineering Dept., Westinghouse Electric & Mfg. Co., E. Pittsburgh, Pa.

RYDER, MALCOLM P., Engineer, Witherbee Igniter Co., Springfield, Mass.

## Members Elected May 19, 1914

BENTLEY, ROBERT O., Division Superintendent, Public Service Electric Co., Newark; res., 70 Gamewell St., Hackensack, N. J.

HISS, FIELDER I., JR., Engineer, Crocker Wheeler Co., Ampere; res., 64 N. 9th St., Newark, N. J.

## Associates Elected May 19, 1914

ALEXANDER, WALTER N., Division Electrician, C. G. W. R. R. Co.; res., 314 10th Ave., Council Bluffs, Ia.

ALLUM, JOHN, Secretary and Sales Manager, National Electrical & Engineering Co. Ltd., Dunedin, N. Z.

BECKER, EDWARD L., Sales Dept., Crocker-Wheeler Co., Ampere; res., 63 Fourth Ave., East Orange, N. J.

BENEDICT, ERIC G., Construction Engineering, Crocker-Wheeler Co., 2nd National Bank Bldg., New Haven, Conn.

BOYDEN, LEWIS L., Electrical Construction Foreman, Isthmian Canal Commission, Miraflores Locks; res., Y. M. C. A., Corozal, C. Z.

BRITT, OSCAR L., Instructor in Electrical Engineering, Oklahoma Agricultural and Mechanical College, Stillwater, Okla.

BULLARD, LESTER H., Foreman Testing, Isthmian Canal Commission, Gatun, C. Z.; res., Evansville, Wis.

BUNDY, OSCAR H., Chief Engineer, Washington & Old Dominion Ry., 3506 M. St. N.W., Washington, D.C.

CARPENTER, RANDOLPH H., Sales Engineer, Westinghouse Electric & Mfg. Co., 165 Broadway, New York, N. Y.

CHU, FU I., Electrical Engineering Student, University of Wisconsin, 709 University Ave., Madison, Wis.

CHUNG, NGO PINFORE, Electrical Engineering Student, University of Wisconsin, 709 University Ave., Madison, Wis.

DEACON, RALPH W, Metallurgical Superintendent, British America Nickel Corp., Ltd.; res., 285 Cedar St., Sudbury, Ontario.

DYE, IRA W., General Foreman, Cristobal-Balboa Transmission Line, Pedro Miguel, C. Z.

ELY, FRANK H., Lineman, Isthmian Canal Commission, Corozal, C. Z.

FALCKE, JOSEPH, Electrician in Charge, Lonely Mine, near Bulawayo, Rhodesia, South Africa.

FITZPATRICK, WILLIAM L., Wireman, Isthmian Canal Commission, Corozal, C. Z.; res., Fairmount, Ind.

FREEMAN, J. STUART, Patent Attorney, 15th and Chestnut Sts., Philadelphia, Pa.

GROVE, RICHARD A., Foreman, Isthmian Canal Commission, Pedro Miguel, C. Z.

HARDING, GEORGE, Manager, Kaatenai Power Co., Paulsen Building, and Consumers Co., 1105 Paulsen Building, Spokane, Wash.

HELLENTHAL, JOSEPH, Foreman, Electrical Construction, Puget Sound Traction, Light and Power Co., Seattle, Wash.

HOLLOWAY, FREDERICK J. H., Electrical Engineer, Noyes Bros. (Sydney) Ltd., 115 Clarence St., Sydney, N. S. Wales, Australia.

HOLZ, M. HARRY, Chief Line Inspector, Electrical Bureau of Philadelphia; res., 1902 N. 11th St., Philadelphia, Pa.

JOBSON, ARTHUR JAMES, Cost Engineer, Phoenix Construction Co., Brigham City, Utah.

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JUNCKER, EMIL W., Mechanical Engineer, Guanajuato Power & Electric Co., Guanajuato; res., El Sabino, Curimeo, Mich., Mexico.

KIMBALL, JAMES MADISON, Asst. Construction Engineer, Providence Telephone Co.; res., 12 Montague St., Providence, R. I.

KING, EVERT E., Draughtsman, Baker Iron Works; res., 2289 W. 24th St., Los Angeles, Cal.

LANSING, FREDERICK MCKAY, Night Chief Operator, Postal Telegraph-Cable Co., Omaha, Nebr.

LARKIN, J. E., Construction Dept., General Electric Co., Pittsfield, Mass.; res., 527 Schenectady St., Schenectady, N. Y.

LESLIE, WILLIAM TREMAINE, Chief Electrician, Mackenzie, Mann & Co.; res., 3371 Greenshields Ave., Montreal, Quebec.

MARSH, FRANK L., Electrical Draftsman and Inspector, Public Service Co. of Northern Illinois; res., 15 Chalmers Place, Chicago, Ill.

MAUS, GEORGE C., Electrical Engineer Service Dept., Westinghouse Electric & Mfg. Co., 37 Wormwood St., Boston, Mass.

MERCER, JAMES M., Engineer, Sales Dept., Mine Div., Jeffrey Mfg. Co., Pittsburgh, Pa.; res., 1676 N. High St., Columbus, Ohio.

MILLAN, WALTER H., Head Operator of Substations, Union Electric Light & Power Co., res., 5803a N. Market St., St. Louis, Mo.

MITROVITCH, MILAN S., Electrician, Pacific Gas & Electric Co., Drum, Placer Co.; res., 1755 Hyde St., San Francisco, Cal.

MOORE, IRVEN W., Electrician, Williamsburg, Iowa.

MORE, CHARLES H., Engineering Dept., American Can Co., 447 W. 14th St., New York, N. Y.

NELLIS, WAYNE H., Wireman, Isthmian Canal Commission, Corozal, C. Z.; res., Pawnee, Okla.

NEUS, HARRY E., Representative, Richmond Electric Works, 30 Church St.; res., 454 E. 116th St., New York, N.Y.

OWENS, ROY, Supt., Operating Dept., Automatic Electric Co.; res., 7410 Crandon Ave., Chicago, Ill.

PARKER, H. V., Electrical Foreman, Isthmian Canal Commission, Gatun, C. Z.; res., Newark, Ohio.

PAUL, CLAUDE WILLIS, Engineer, Western Electric Co., 463 West St., New York, N. Y.

PERRY, BERTWIN L., Supt. Engineering Dept., Burnham Frith Electric Co. Ltd., Edmonton, Alta.

SATO, YASUNORI, Assistant Engineer, Inawashiro Hydro-Electric Power Co. Ltd., Tokyo, Japan.

SCHIRTZINGER, FRANK E., Superintendent, Middletown Gas & Electric Co., Middletown, Ohio.

SCHULER, LEO, General Secretary, Elektrotechnischen Vereins, Tulpenstrasse 5, Berlin-Lichterfelde, Germany.

SHIRE, HARRY I., Sales of Electrical Apparatus, 1310 Majestic Building, Detroit, Mich.

SHOLL, WILLIAM E., Sub-Station Construction, Washington Water Power Co., Mullan, Idaho.

SILVER, NATHANIEL H., Manager, Seattle Office, Pierson Roeding & Co., 522 Colman Bldg., Seattle, Wash.

SMITH, HAROLD REGINALD, Asst. Electrical Engineer, 320 City Hall, Toronto, Ontario.

STANGE, HARRY D., Electrician, 723 N. Spaulding Ave., Chicago, Ill.

WILCOX, RALPH B., Salesman, Standard Underground Cable Co., 700 Westinghouse Bldg., Pittsburgh, Pa.

WILSON, ALEXANDER, Asst. Designing Engineer, Cedar Rapids Mfg. & Power Co., Power Bldg., Craig St., Montreal, Que.

WOODHOUSE, GEORGE E. General Foreman, Toronto Power Co., Toronto, Ont.

WRIGHT, CLYDE F., Wire Chief, Postal Telegraph-Cable Co., 319 Fourth St., Des Moines, Iowa.

Total 54.

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## Applications for Election

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before June 30, 1914.

Adams, H. J., Moscow, Idaho.
Albright, A. S., Detroit, Mich.
Bell, A. L., Culebra, C. Z.
Brightbill, F. G., Connellsville, Pa.
Brunet, R. L., Providence, R. I.
Bullock, O., Pedro Miguel, C. Z.
Burroughs, F. F., Oxford, Mich.
Caley, R. D., Corozal, C. Z.
Carlson, A. U., Spokane, Wash.
Chamberlin, G. N., Lynn, Mass.
Connell, C. W., Corozal, C. Z.
Cook, C. G., New York, N. Y.
Cordier, G., Paris, France.
Crawford, E. J. (Member), Fresno, Cal.
Duncan, T. C. (Member), Prince Rupert, B. C.
Feehan, J. H., Jr., Gatun, C. Z.
Fenton, M. F., San Diego, Cal.
Fletcher, J. Y., London, England.
Hall, F. S., Lynn, Mass.
Horn, A. R., Washington, D. C.
Hull, S. P., Topeka, Ind.
Johnstone, D. M., Vancouver, B. C.
Kleene, W. F., Balboa, C. Z.
Koch, R., Pittsburgh, Pa.
Kostko, J. K., St. Louis, Mo.
Lehmpuhl, H. F., Chicago, Ill.
Leonard, L. D., Cleveland, S. Africa.
Lyman, V. A., Corozal, C. Z.
McElroy, B., Spokane, Wash.
Mertens, B. de M., Vancouver, B. C.
Moffet, F. V., Jr., Kelowna, B. C.
Mort, W., New York, N. Y.
Moy, Frank, Philadelphia, Pa.
Nagahama, S., Schenectady, N. Y.
Nordwald, B., Los Angeles, Cal.
Owens, P. R. (Member), New York, N. Y.
Ramsay, A. T., Atlanta, Ga.
Rathbun, B. C., Cannonsburg, Pa.
Riddick, A. G., Gurley, Ala.
Robbins, T. W., Olmstead, Utah.
Roosevelt, J. K., Panama, Panama.
Runyon, F. O. (Member), Newark, N. J.
Russell, B. C., Boise, Idaho.
Sample, R. M., New York, N. Y.
Sara, R. A., Winnipeg, Manitoba.
Schou, T., Minneapolis, Minn.
Schroeder, J. H., Atlanta, Ga.
Sinclair, R., Redondo Beach, Cal.
Smith, V. L., Los Angeles, Cal.
Thompson, L. W., Buffalo, N. Y.
Tucker, F. A., Milwaukee, Wis.
Webster, R. A., Bozeman, Mont.
Wilson, L. A., Berkeley, Cal.

## Students Enrolled May 19, 1914

6512 Fernandez, F., Armour Inst. Tech.
6513 Mertz, R., Ohio Northern Univ.
6514 Lagaard, A.S.T., Univ. of Minn.
6515 Meddaugh, E. S., Univ. of Calif.
6516 Cowle, W. W., Ohio State Univ.
6517 Walters, E., Ohio State Univ.
6518 Chilcote, L. R., Univ. of Calif.
6519 Brown, W. D., Univ. of Toronto.
6520 Dashley, L. H., Univ. of Wash.
6521 Hamilton, F. F., Purdue Univ.
6522 Lebo, W.F., Purdue University.
6523 Aldrich, H.P., Purdue University.
6524 Ringwalt, P.C., Kans. St. Agri. Coll.
6525 Parkerson, L.R., Kan. St. Agr. Coll.
6526 Danner, E.C., Carnegie Inst. Tech.
6527 Sontum, W.C., Carnegie Inst. Tech.
6528 Richter, O.G., Carnegie Inst. Tech.
6529 Diehl, G. S., Carnegie Inst. Tech.
6530 Kirk, R. L., Carnegie Inst. Tech.
6531 Oakes, H., Carnegie Inst. Tech.
6532 Wilson, J.R., Carnegie Inst. Tech.
6533 Weber, V. E., Oregon Agri. Coll.
6534 Asplund, W., Oregon Agri. Coll.
6535 Ulangold, A.O., Oregon Agri. Coll.
6536 Mei, Y.C., Worcester Poly. Inst.
6537 Hildebrandt, E., Lewis Institute.
6538 Merrick, C. B., Univ. of Calif.
6539 Ferguson, D.G., Univ. of Toronto.
6540 Thompson, H. E., Univ. of Ill.
6541 O'Hagan, B. E., Univ. of Pitts.
6542 Howard, D.G., Worcester Poly. Inst
6543 Gaines, F.C., Georgia Sch. Tech.
6544 Todd, W.B., Lehigh University.
6545 Garrow, E.E., McGill University.
6546 MacLeod, H. J., McGill Univ.

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6547 Tull, W. S., Univ. of Toronto.
6548 Atwell, C.A., Univ. of Nebraska.
6549 Leavitt, A.R., Worcester Poly. Inst.
6550 Jackson, W.H., Georgia School Tech
6551 Freeman, S., Georgia Sch. Tech.
6552 Hall, H.J., Rensselaer Poly. Inst.
6553 Weber, C.F., Rensselaer Poly. Inst.
6554 Brinkmeier, A.E.H., Univ. of Mo.
6555 Hennesy, E. N., Worcester Poly. Institute
6556 Wagner, L.E., Ohio Northern Univ.
6557 Simonich, J. L., Univ. of Illinois.
6558 Wiebmer, A. H., Univ. of Illinois.
6559 Miller, C., Washington University.
6560 Field, S. B., Washington Univ.
6561 Claxton, W.L., Georgia Sch. Tech.
6562 Peacock, W.C., Georgia Sch. Tech.
6563 Woodruff, B.H., Jr., Ga. Sch. Tech.
6564 Hart, R.E., Case Sch. App. Science.
6565 Stevenson, H.M., Miss. A. & M. Coll.
6566 Stoneman, E.C.R., Univ. of Tor.
6567 Mills, P. H., Univ. of Toronto.
6568 Perkins, K. A., Tufts College.
6569 Young, G. D., Throop Coll. Tech.
6570 Knapp, L. E., Univ. of Missouri.
6571 Creasey, J.W., Univ. of Missouri.
6572 Vulling, J., Wentworth Institute.
6573 Holland, W. H., Univ. of Calif.
6574 List, E. G., Univ. of Missouri.
6575 Pratt, H., Univ. of California.
6576 Faden, J. L., Tufts College.
6577 Ramsay, H. S., Tufts College.
6578 Doolittle, F. M., Yale Univ.
6579 Morgan, N.L., McGill University.
6580 Huhnhausen, A.E., Ore. Agri. Coll.
6581 Kistler, R.E., Stanford University.
6582 Skolfield, W. K., Stanford Univ.
6583 Dring, G. S., Univ. of Missouri.
6584 Tear, H. R., Univ. of Illinois.
6585 Hattis, R. E., Univ. of Illinois.
6586 Chien, K., Univ. of Wisconsin.
6587 Allcutt, C.T., Stanford University.
6588 Noble, W. H., Ohio State Univ.
6589 Smith, H.L., Mich. Agri. Coll.
6590 Mertz, K.J., Univ. of Minnesota.
6591 Whitehead, E. C., Ga. Sch. Tech.
6592 Hearne, W. D., Ga. Sch. of Tech.
6593 Tuthill, J. R., Univ. of Illinois.
6594 Cumming, R. B., Univ. of Calif.
6595 Clement, L.M., Univ of Calif.
6596 Kenly, W. L., Yale University.
6597 Gemmel, J. S., Lehigh University.
6598 Dean, S. M., Mich. Agri. College.
6599 Tate, P. R., Univ. of Missouri.
6600 Ten Haagen, J. E., Lewis Inst.
6601 Dow, C. A., Univ. of Minnesota.
6602 Geotzenberger, R.L., Univ. of Minn.
6603 Bressler, H. V., Swarthmore Coll.
6604 Wise, L. D., Univ. of Kansas.
6605 Chang, M. Y., Univ. of Wisconsin.
6606 Reed, M. O., Univ. of Wisconsin.
6607 McLees, H.L.B., Penn. St. Coll.
6608 Lee, P. M., Lafayette College.
6609 Temple, F. W., Mich. Agri. Coll.

## Joint Meeting of Engineering Societies in Milwaukee

The Milwaukee and Madison Sections of the A. I. E. E. participated in the Second Joint Meeting of Technical Societies of Wisconsin, held in Milwaukee on March 21, 1914. It was an all-day meeting; the sessions were held in the Juneau Hall at the Auditorium Building.

Following the opening address by Dean Frederick E. Turneaure of the College of Mechanics and Engineering, University of Wisconsin, four papers were presented during the morning session: "Electrical Control on the Panama Canal," by Messrs. E. M. Hewlett and H. G. Hill; "Cement and Clay Products Contrasted," by Mr. Alfred O. Crozier; "The Measurement of Gases in Large Quantities," by Mr. J. C. Wilson; and "The Historical Significance of the 1907 Wisconsin Law for the Regulation of Public Utilities," by Professor R. C. Disque.

During the afternoon session the following papers were presented: "Principles of Illumination," by Mr. John Hayes Smith; "Principles of Street Lighting," by Messrs. Arthur J. Sweet and Francis A. Vaughn; "Manufacture of Pure Iron Products," by Mr. G. F. Ahlbrandt; "History of Drilling," by Mr. H. M. Morris; and "Developments in American Power Plant Machinery," by Professor A. G. Christie.

The evening session was devoted to a paper on "Radium" by Dr. Herbert N. McCoy of the University of Chicago.

The approximate attendance at the

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several sessions was as follows: morning 300; afternoon, 500; evening, 850. Sixteen technical and engineering organizations participated in the meeting, which was successful in every way.

## Past Section Meetings

**Baltimore.**—March 27, 1914, Physical Laboratory, Johns Hopkins University. Subject; Insulation. Paper; "Insulating Materials", by L. E. Barringer. Attendance 26.

April 24, 1914, Bureau of Standards, Washington, D.C. Joint meeting with the Washington Section and held under the auspices of the Electrophysics Committee.

**Boston.**—April 23, 1914, Engineers Club of Boston. Subject; Motor Application. Paper; "Application of Motors to Constant-Torque Adjustable-Speed Work." Attendance 54.

**Cleveland.**—April 20, 1914, Nela Park. Subject; Illumination. Papers; three articles on "The Latest Developments in Incandescent Lamps and Their Application to Modern Lighting", by Evan J. Edwards, Ward Harrison, and M. Luckiesh. Attendance 78.

**Detroit-Ann Arbor.**—April 17, 1914, Adcraft Club. Subject; Storage Batteries. Paper; "Some Power Plant Storage Battery Applications", by Taliaferro Milton. Attendance 47.

**Indianapolis-Lafayette.**—March 26, 1914, Electrical Building, Purdue University. Subject; Railway Electrification. Papers; (1) "Early Work of the General Electric Company in Railway Electrification Projects" by A. L Rohrer; (2) "Some Details of the Electrification of the Butte, Anaconda and Pacific Railway System" by J. H. Linebaugh. Attendance 100.

April 3, 1914, Science Bldg., Indianapolis. Subject; Radioactivity. Paper; "The Present State of Our Knowledge of Radium and Radioactivity", by Herbert N. McCoy. Attendance 110.

**Los Angeles.**—April 28, 1914, Blanchard Hall. Subject; Railway Work. Paper; "Railway Substation Operation," by Julian Adams. Attendance 68.

**Lynn.**—April 8, 1914, Burdett Hall. Lecture on "The Effect of Electrical Engineering on Modern Industry" by Charles P. Steinmetz. Attendance 393.

**Minnesota.**—April 13, 1914. University of Minnesota. Subject; Illumination. Papers; (1) "Lighting of the Gordon-Ferguson Building in St. Paul" by A. L. Abbott; (2) "Show Window Lighting" by C. M. Converse; (3) "Efficiency Test on Semi-Indirect Lighting Units Used in Gordon-Ferguson Building" by R. B. Wallace. Attendance 50.

**Panama.**—March 10, 1914, Y. M. C. A., Gatun, C.Z. Subject; Illumination. Paper; "Illumination of Panama Canal Locks," by W. R. McCann and F. C. Clark. Also data on installation by S. H. Grauten. Inspection trip to adjacent locks. Attendance 71.

**Philadelphia.**—April 13, 1914, Engineers' Club. Subject; Telephony. Papers; (1) "The Loading of Telephone Circuits", by H. Mouradian; (2) "Emergency Work," by H. C. Kunkel; (3) "Telephone Train Despatching" by G. K. Heyer. Attendance 133.

May 11, 1914, Engineers Club. Subject; Railway Work. Paper; "The Battery Locomotive," by L. H. Flanders. Attendance 50.

**Pittsburgh.**—February 14, 1914, Fort Pitt Hotel. Annual Banquet of Pittsburgh Section. Addresses; "The Institute" by C. O. Mailloux; "Rates" by Paul M. Lincoln; "Making of an Engineer" by W. M. Davidson; "Stomatology" by Geo. P. Early. Attendance 300.

March 10, 1914, Oliver Building. Subject; Industrial Power. Paper; "Practical Speed Control of Alternating-Current Roll Mill Motors", by G. E. Stoltz. Attendance 60.

**Portland.**—March 3, 1914. Hawthorne Building. Subject; Railway Electrification. Paper; "Electrification of the Portland, Eugene and Eastern Railway System" by Paul Leben-

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baum. Joint meeting with Portland Section of N. E. L. A. Attendance 70.

April 7, 1914, Hawthorne Building. Subject; Underwriters' Inspection. Paper; "Is Underwriters' Inspection Necessary in Oregon," by F. D. Weber. Also illustrated lecture on "The Panama Canal and Its Electrification" by D. B. Rushmore, presented by E. A. West. Joint meeting with Portland Section of N.E.L.A. Attendance 95.

**San Francisco.**—February 27, 1914. Engineers' Club. Subject; Public Service. Paper; "Policy of Public Service Corporations" by John A. Britton. Attendance 100.

March 27, 1914, Engineers' Club. Subject; Economics. Paper; "Economics of the Production and Distribution of Electric Power," by C. L. Cory. Attendance 65.

**Schenectady.**—March 10, 1914. Edison Club Hall. Subject; Illumination. Paper; "Light, Shade and Color in Illumination," by M. Luckiesh, with illustrations. Attendance 400.

March 24, 1914, Edison Club Hall. Subject; Lighting from Central Stations. Brief addresses were given by Messrs. E. P. Edwards, C. W. Stone, S. E. Doane, L. A. Hawkins, J. R. Tapscott, W. S. Andrews, L. B. Bonnett and H. R. Summerhayes. Attendance 225.

April 7, 1914, Edison Club Hall. Subject; Panama Canal. Paper; "Panama Canal Emergency Dams," by O. E. Hovey, illustrated with lantern slides. Attendance 375.

April 21, 1914, Edison Club Hall. Subject; Alternating-Current Machinery. Brief addresses were given by Messrs. E. C. Knowlton, R. E. Doherty, E. H. Freiburghouse, A. E. Averett, and M. H. Wells. Attendance 200.

**Seattle.**—March 4, 1914, University of Washington. Subject; Transformers. Paper; "The Effect of Star and Delta Connections on Transformer Wave Forms," by L. F. Curtis. Joint meeting with University of Washington Branch. Attendance 45.

March 17, 1914, Central Building. Subject; Protective Apparatus. Discussion on "Protective Reactances in Large Power Stations" by Messrs. Lyman, Rossman and Perry; abstracted by Mr. Terrell. Attendance 21.

April 18, 1914, Central Building. Subject; Engineering Ethics. Paper; "Engineering Ethics" by Robert Howes. Attendance 23.

**Spokane.**—February 20, 1914, Silver Grill. Subject; Regulation of Public Utilities. Address by Mr. Henry L. Gray, former chief engineer Washington State Public Utilities Commission. Also address on Panama Canal by J. C. Ralston, illustrated with lantern slides. Attendance 53.

March 20, 1914, Silver Grill. Papers: "Underground Duct Lines" by F. L. Rohrbach; "Rate Practise and Justification" by T. E. Holsey. Attendance 48.

**Toledo.**—April 3, 1914, Willys-Overland Company. Inspection trip through Willys-Overland automobile plant. Attendance 38.

May 6, 1914, Toledo Commerce Club. Subject; Motor Control. Address on "Remote Control of Motors" by W. H. Lennard, illustrated with lantern slides. Attendance 18.

**Toronto.**—March 6, 1914, University of Toronto. Subject; Railway Electrification. Paper; "High-Tension Direct-Current Railways," by G. H. Hill, illustrated by motion pictures. Attendance 125.

March 27, 1914, Engineers' Club. Subject; Water Power Development. Paper; "The Influence of Ice on Water Power Development," by H. T. Barnes, illustrated with lantern slides. Attendance 52.

April 17, 1914, Engineers' Club. Subject; Transmission. Paper; "Stand-by Steam Stations for Overhead Transmission Systems" by C. G. Spencer. Attendance 42.

**Urbana.**—April 16, 1914, Physics Building. Paper; "Magnetic and Other Properties of Electrolytic Iron Melted

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in Vacuo" by T. D. Yensen. Attendance 57.

**Vancouver.**—March 27, 1914. University Club Rooms. Subject; Rheostats. Paper; "Liquid Rheostats," by C. N. Beebe.

## Past Branch Meetings

**University of California.**—April 16, 1914. Mechanical Building. Election of Officers. No technical session. Attendance 25.

**University of Cincinnati.**—May 5, 1914, Engineering Building. Subject: Illumination. Address by Prof. A. M. Wilson illustrated by lantern slides. Attendance 34.

**Colorado State College.**—April 23, 1914, Electrical Engineering Building. Address by Mr. D. F. Richardson on Western Electric Company's Chicago Works. Attendance 10.

**University of Colorado.**—April 15, 1914, Boulder, Colo. Address by Mr. M. C. McCormick on Commonwealth Edison Company of Chicago. Attendance 35.

**Iowa State College.**—April 22, 1914, Ames, Iowa. Address by Prof. J. E. Brindley on "Relation of Our Government to Public Utilities".

**Lafayette College.**—April 20, 1914, Pardee Building. Paper "The Qualifications of a Good Engineer," by M. Conklin. Election of officers. Attendance 20.

April 27, 1914, Pardee Building. Papers: "Thesis Work on Motor-Generator Set," by Simmons and Mitchell; "Exhaust Steam Turbine," by J. Meyer; "Mercury Turbine," by R. Smith. Attendance 22.

May 4, 1914, Pardee Building. Papers: "Electrolysis from Stray Electric Currents," by Laros, Thompson and Clymer; "Diehl Machine" by Shimer and Kolb; "Electric Headlight for Steam and Electric Lines" by Davidson. Attendance 22.

**Lehigh University.**—April 30, 1914, Physical Laboratory. Paper: "A Description of the Electrical Development of the Bethlehem Steel Company's Iron Mines in Chile," by W. S. Bourlier. Attendance 24.

**University of Missouri.**—April 20, 1914, Engineering Building. Subject: Causes, Prevention and Treatment of Accidents. Addresses were given by Messrs. C. C. Boswell and F. W. Anderson.

May 5, 1914, Engineering Lecture Room. Illustrated lecture by Prof. H. W. Hibbard on Engineering Societies Building, New York. Attendance 23.

**Montana State College.**—May 6, 1914, Paper: "The Effect of Electricity on the Growth of Plants," by S. H. Solberg. Election of officers. Attendance 27.

**University of Nebraska.**—April 8, 1914, Electrical Building. Subject; Constant Current Machinery. Brief addresses by Messrs. D. E. Ahrens, J. F. Formanek, and Charles W. Beck. Attendance 24.

April 29, 1914, Electrical Building. Subject: The Oscillograph. Paper; "An Experimental Investigation with the Oscillograph," by C. A. Atwell. Attendance 14.

**Ohio Northern University.**—April 1, 1914, Ada, Ohio. Addresses were given by Messrs. C. R. Billheimer, R. W. Bricker, and J. H. Homrighous, on inspection tour of March 2 to 7 inclusive. Attendance 19.

**Ohio State University.**—March 13, 1914. Robinson Laboratory. Papers: "X-Rays," by Howard T. Bryan; "Long-Distance Telephony and Telegraphy," by R. B. Shenck. Attendance 23.

March 25, 1914, Robinson Laboratory. Subject: Railway Electrification. Illustrated lecture by Messrs. A. L. Rohrer and J. J. Linebaugh on "Electrification of the Butte, Anaconda and Pacific Railroad." Attendance 85.

April 1, 1914, Robinson Laboratory. Discussion on arrangements for electrical show. Attendance 30.

**Oklahoma University.**—March 4, 1914, Engineering Building. Paper:

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"Review of Progress in 1913," by Clarence Karcher. Also discussion of Institute papers on outdoor substations by Messrs. Macomber, Fullerton, Hunt, and Perry. Attendance 14.

March 11, 1914, Engineering Building. Address by Mr. Barnes on "Recent Development in Induction Motor Design."

**Oklahoma A. and M. College.**—March 19, 1914, Stillwater. Discussion of Institute papers "Notes on Oil Circuit Breakers" by K. C. Randall, and "Problems of High Tension Transmission Lines." Attendance 21.

March 26, 1914, Stillwater. Discussion of "Sixty-Cycle Synchronous Converters" by L. P. Creecelius, and Power from Mercury Vapor" by W. L. R. Emmet, as printed in March PROCEEDINGS. Attendance 21.

**Oregon Agricultural College.**—February 26, 1914, Corvalis, Oregon. Discussion on "Wood Preservation" by H. S. Newins, and "Strength of Materials," by H. S. Graf. Attendance 19.

**University of Oregon.**—March 3 1914, Electrical Building. Paper: "Water Rights," by C. B. Aitchison. Attendance 30.

April 7, 1914, McClure Hall. Second address on "Water Rights" by C. B. Aitchison. Attendance 15.

**Pennsylvania State College.**—March 19, 1914, Club Room, Engineering Building. Papers: "Tirrell Regulator" by E. W. Gibbs; "Axle Generator System" by A. D. Shultz. Attendance 42,

**Purdue University.**—April 9, 1914. Paper: "The Technical Graduate in Business," by W. M. Skiff. Attendance 68.

April 21, 1914. Paper "Salesmanship," by R. A. Prescott, Attendance 37.

May 5, 1914. Paper: "Recent Developments in Incandescent Systems," by H. H. Magdsick, illustrated with lantern slides. Attendance 31.

**Rensselaer Polytechnic Institute.**—March 3, 1914, Sage Laboratory. Papers: "Thermal Electromotive Forces of Alloys Made from the Base Metals," by A. B. Hayck; "A Compound Transformer," by M. S. Cower. Attendance 41.

April 7, 1914, Sage Laboratory. Papers: "The Effect of Various Materials on the Conductivity of Cast Copper" by D. K. Macken; "A Hydroelectric Development in Cuba," by P. C. Rummel; "A Three-Phase Hiroult Furnace Installation," by H. F. Wilson. Attendance 49.

**Rhode Island State College.**—February 25, 1914, Science Hall. Subject Lightning Protection. Addresses were given by Messrs. Whittaker, Miller and Cloke, with demonstrations. Attendance 30.

March 18, Science Hall. Subject: Aluminum Lightning Arresters. Addresses were given by Messrs. L. H. Harris and W. H. Webb. Prof. Dickenson gave demonstration of the action of aluminum arresters. Attendance 20.

**Rose Polytechnic Institute.**—January 17, 1914, Heminway Memorial Hall. Papers: "Resuscitation," by Turner; "Pulmotor" by Dr. Alexander. Discussion of automobile lighting by Walker H. Henry. Attendance 23.

**Stanford University.**—March 12, 1914, Electrical Engineering Building. Discussion on Branch matters. Attendance 14.

March 18, 1914, Electrical Engineering Building, Illustrated lecture by Mr. Allen G. Jones on "Lightning Arresters and Protective Devices." Attendance 24.

April 9, 1914 Electrical Engineering Building, Papers: "White River Hydroelectric Development" by C. T. Alcutt; "Modern X-Ray Studies and Equipment" by A. B. Stuart; "Wireless Telephony" by W. Skolfield. Attendance 26.

April 23, 1914, Electrical Engineering Building. Papers: "The Bennet Lightning Arrester" by W. L. Cone; "Illuminating Efficiencies" by R. E. Kistler; "Electricity in Agriculture" by M. T. Rodig; "Progress in the San Joaquin Valley" by L. A. Ogden. Attendance 12.

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April 30, 1914, Electrical Engineering Building. Lecture by Prof. H. J. Ryan on "High Frequency High Voltage Phenomena." Attendance 50.

**Syracuse University.**—March 5, 1914. Paper: "The Control Board of Panama Canal Locks" by B. H. Kenyon. Report by Mr. F. C. Funnell on State control and development of water power rights in New York, and performance of storage battery cars during recent heavy snow storms. Attendance 11.

March 12, 1914, Mr. M. C. Davison gave an address on "Corona Phenomena." Mr. H. A. Smith reported on current events in electrical engineering. Attendance 16.

March 19, 1914. Symposium on "Use of Electric Motors," by J. F. Reynolds, E. S. Radway, and I. R. Baker. Attendance 12.

March 26, 1914. Address by Mr. R. N. Brockway on "Mercury Turbines." and "Condenser Type Terminals" by G. H. Burns. Attendance 11.

April 16, 1914, Paper: "Operation of Transmission Lines," by John Ginley. Attendance 11.

**Texas A. and M. College.**—March 3, 1914, Electrical Engineering Building Auditorium. Paper: "Manufacture of Telephone Cables," by W. L. Harper, illustrated with stereoptican. Attendance 33.

March 20, 1914, Lecture Room. Illustrated lecture by Mr. Ritter on "Motors." Attendance 58.

April 3, 1914, Lecture Room. Paper: "High Power Transmission Lines," by D. H. Lefy. Attendance 20.

April 10, 1913, Lecture Room. Paper "Quality; in Men and Machinery," by C. A. Nash; "Electric Elevators," by J. M. Vossler. Attendance 24.

**Throop College of Technology**—February 28, 1914, Throop College. Papers: "The Design of an Automobile Testing Plant," by H. B. Gerckens; "The Relation between Mechanical Flaws and Magnetic Measurements in Metals," by Virgil F. Morse; "Y versus Delta Connections in Transmission Systems," by Walter T. Newton. Attendance 75.

**University of Virginia.**—February 17, 1914, Mechanical Laboratory. Discussion of Mr. W. L. R. Emmet's paper on "Power from Mercury Vapor," as published in PROCEEDINGS. Attendance 10.

**University of Washington.**—March 4, 1914, University Campus. Paper: "The Effect of Star and Delta Connections on Transformer Wave Forms," by L. F. Curtis. Attendance 45.

April 14, 1914, University Campus. Paper; "The Hydroelectric Plant of the Olympic Power Company," by W. A. Danielson. Attendance 30.

**Worcester Polytechnic Institute.**—March 13, 1914. Abstracts of Institute papers were presented by Messrs. G. S. Vernam and Y. C. Mei. Attendance 40.

April 17, 1914, Worcester, Mass. Paper: "Some Phases of the New Haven Electrification System," by M. F. Clement. Attendance 75.

May 8, 1914, Worcester, Mass. Papers; "The Distortion of Wave Form in Transformers Caused by Silicon-Steels" by Y. C. Mei; "A Study of Brake-Shoe Pressure" by G. W. Nelson "The Development of Quick Workable Curves for Transmission Line Data," by G. S. Vernam; "Experimental Data and Theoretical Formula for Elastic and Non-Elastic Catenary," by G. I. Gilchrest.

**Yale University.**—March 11, 1914, New Haven, Conn. Professor W. S. Franklin of Lehigh University gave an address on "Couple Circuits of Wireless Telegraphy." Attendance 200.

March 27, 1914, New Haven, Conn. Mr. S. L. Nicholson gave an address on "Commercial or Application Engineering." Attendance 100.

April 22, 1914, New Haven, Conn. Mr. W. S. Murray delivered an address on "The Electrification of the New Haven Railroad." Attendance 175.

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## Personal

MR. ALLEN C. MORSE has been chosen as resident engineer and manager of the new branch office which the engineering firm of McMeen and Miller has opened in Cleveland, Ohio, at 407 Electric Building. The firm has been conducting a general engineering practise for more than ten years. The main office of McMeen and Miller is at 1454 Monadnock Block, Chicago, Ill.

MR. LOUIS B. MAGID, who was president of the Atlanta Hydro-Electric Power Company until that company was consolidated with the Georgia Railway and Power Company of Atlanta, is developing a large commercial apple orchard of some 5000 acres at Tallulah Park, Georgia, near the waterpower development at Tallulah Falls. Mr. Magid is president of the Appalachian Electric Power Company and is also head of the banking firm of Louis B. Magid and Company of Atlanta.

## Obituary

BERT ERNEST SEMPLE, Assoc. A. I. E. E., sales agent in the power and mining department of the General Electric Company, died on May 15, 1914. Mr. Semple had been connected with the General Electric Company for the last twenty-one years, having started in the lamp repair department in 1893. Later in that year he took charge of the meter work, being the first man to handle this line for the company in the Chicago district. In 1904 he was appointed superintendent of the Chicago repair department of the General Electric Company, and after serving in this capacity for four years he was transferred to the sales organization, where as sales agent in the power and mining department he handled principally the larger apparatus used in the manufacture of steel, his business being chiefly with the large steel plants throughout the middle West. Mr. Semple was elected an Associate of the A. I. E. E. on November 21, 1902. He was also a member of the Association of Iron and Steel Electrical Engineers.

## Abstracts of Proceedings of Foreign Engineering Societies

### ELEKTROTECHNISCHER VEREIN

Paper of Mr. Bruno Thieme at the meeting in Berlin, February 3, 1914, on "Electrical Sensitiveness of Flames and Its Utilization."

The speaker found that by direct current carbon may be obtained from a candle flame. To do this, he introduces into the flame two electrodes with a potential of 15 volts between them; the carbon deposits then in a thin layer on the negative electrode. This process was reproduced by means of a projection camera. The speaker worked out a special process for obtaining carbon based on this phenomenon. The carbon thus obtained is said to be particularly fine, and especially convenient for the dye industries. The speaker has further noticed that when the circuit is closed, a noticeable pulsation of the flame occurs, and proposes to use this phenomenon for the production of a simple telephone receiver and for other purposes.

Paper of Dr. Linke at the same meeting on "Excess Currents and Excess Voltages Occurring when Placing in Circuit Alternating-Current Motors and Transformers."

The speaker pictured the rise of excessive currents when inductances are placed in circuit. When a preeminently inductive circuit is joined to an alternating potential, the placing in circuit occurring in the neighborhood of the zero point of the voltage curve, the magnetic field, during the first period after the new source of current has been switched in, becomes approximately twice as strong as it normally is. If now the iron contained in the magnetic circuit is near its point of saturation when the flux is of normal magnitude, with this double strength of the

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field there occurs an excessive saturation, as a result of which the charging rate may rise to one hundred times that of the normal exciting current. This powerful rise of current is particularly undesirable when motors and transformers are inserted in circuit, since it brings into action the maximum automatic cut-out devices. The surge of current may be prevented by means of switches with more than one contact point, so that the apparatus is placed in circuit over a resistance.

A special case is that of placing in circuit asynchronous motors with squirrel-cage rotors when the latter have been already brought by outside influences to nearly synchronous speed. In this case, owing to the phenomena which take place at the instant of the motor being placed in circuit, the normal rotating field is not available at once, and for some time the rotor moves in a nearly stationary field, which is apt to produce violent short-circuit currents.

The speaker passed then to the consideration of excessive currents which arise when generators are short-circuited, and which cause the windings of these machines to be subjected to extremely high mechanical stresses. To obviate such short-circuit currents, choke coils are sometimes inserted in a permanent manner in front of generators. But this method can be used only to a limited extent, and the apparatus must be built so as to be able to withstand the stresses which may arise at short-circuit.

The author proceeded then to discuss the distribution of static voltages occurring when motors and transformers are placed in circuit, at which time, owing to the reflection of the voltage wave by the self-induction of the windings, there may be difference of potential between the windings approaching in magnitude the total working voltage. These dangerous over-voltages could also be obviated by means of a switch with several contacts. The subject of these "wandering waves" was only briefly touched upon by the speaker, and left over to be treated fully in the course of lectures beginning on February 16.

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### Societe Internationale des Electriciens

"Contributions towards the production of strong magnetic fields and the concentration of ampere-turns in a small volume," by Deslandres and Perot.

M. Perot presents to the Société Internationale des Electriciens at the meeting of March 4, 1914, both in the name of M. Deslandres and himself, the new results that they have obtained in the construction of electromagnets.

To obtain strong magnetic fields we can use two methods:

(1) One can produce a high flux of induction in a magnetic circuit and concentrate, by means of cone shaped polar pieces, the flow in an air gap of small cross-section and small length. It is this very principle which is used with so much success by P. Weiss in constructing his electromagnets and especially his remarkable models.

(2) One can work with the magnetic properties of the current, without however, using any magnetic medium; this is the solution offered by Perrin and Fabry. This last procedure necessitates a very great concentration of ampere-turns and therefore the use of high-tension current densities.

The authors have worked out a method in which the magnetising circuits act on the air gaps themselves of a magnetic circuit, having as small a resistance as possible; the polar pieces instead of concentrating it, as is the case in the present apparatus, (hold), so to speak, the flux, and we can thus obtain very strong magnetic fields.

The realization of this apparatus depends on the possibility of obtaining very high current densities, and this problem has therefore been approached first. A solution has been found by using as conductors strips of red copper

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of about tenth of a millimeter thickness, cooled by a flow of oil, carried at as low a temperature as possible. In the tests made by the authors, it was possible by using oil at about—25 deg., to obtain 1800 amperes per square millimeter for strips 1/10 mm. thick and 1500 for those of 2/10 mm. thickness. A coil constructed on these dimensions having a core of 30 mm. and a volume of 29 cu. cm. gave 30,800 ampere-turns, the real density being 500 amperes, and the effective density 200 amperes.

This coil was then placed in such a way as to act on the air gap of a Weiss electromagnet, old model, and increased the field from 41,000 gausses to 51,500, the air gap being 2.1 mm. and about 3 mm. diameter; the polar pieces being of ordinary iron. They have thus obtained the highest possible magnetic field under the given air gap conditions.

They have then constructed a special electromagnet, based on the facts given above; the apparatus, which weighs some thirty kilograms, can receive a current of 4000 amperes; the current at the disposal of the authors did not yield more than 1900 amperes; under these conditions the polar pieces were provided with ferro-cobalt of about 12 mm. diameter, and the air gap was 1.7 mm. long and 3 mm. diameter. The field obtained was as high as 50,500 gausses.

If one could have obtained a current of 4000 amperes, the field would have been nearly 60,000 gausses or more.

M. Perot said that the two problems —obtaining the maximum force in a small space, and producing a strong field in a great air gap—although in appearance different, are really connected; thus an electromagnet of the model presented to the society, but weighing about 3000 kg., would permit one to obtain more than 60,000 gausses in a cylindrical air gap of 8.5 mm. length and 15 mm. diameter; one could not foresee with accuracy what would be the field obtained with a similar apparatus using an air gap 2 mm. long and 3 mm. diameter.

Moreover, the question of cooling has not been studied entirely; M.M. Deslandres and Perot intend to take up this question in connection with M. Claude; as to the tests with the apparatus itself, their studies have been interrupted owing to lack of funds; they hope however, to overcome this difficulty and proceed with their experiments.

## Periodicals Wanted for the Library of the Engineering Societies

The Library Board of the United Engineering Society desires to obtain by gift, exchange or purchase any of the missing volumes of serial publications listed below, and requests the cooperation of members of the Institute. Those who have any of these volumes, or know of anyone who wishes to dispose of them, are requested to notify Dr. W. P. Cutter, Librarian, Library of the Engineering Societies, 29 West 39th Street, New York. Coöperation in this matter will be of great assistance in adding to the resources of the Library.

WANT LIST

Acetylene Journal, 1-13, 1899-1912.
Acetylen in Wissenschaft und Industrie, 1-12, 1898-1909.
Acetylene, 1-5, 1903-1908.
Aeronautical Journal, 1-12, 1897-1908.
Allgemeine Automobil Zeitung, 1-9, 1900-1908 (Berlin).
Allgemeine Bauzeitung, 1-date, 1836-date.
American Lumberman, 1-date, 1899-date.
Annalen der Chemie (Liebig's), 1-364, 1832-1909.
Annales des Mines de Belgique, 1-8, 1896-1903.
Annales des Ponts et Chaussées. Memoires et documents. Ser. 1-5; Ser. 6, vols. 1-16, 19-end of ser.; Ser. 7; Ser. 8, vols. 1-30, 36.
——— Lois decrets, etc. Ser. 1-5; Ser. 6, vols. 1-8, 10-end of ser.; Ser. 7; Ser. 8, vols. 1-7, 8 pt. 1.
——— Personnel. All before 1889, and any issued to date.
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Cement and Engineering News. 1-21, 22, no. 2, 1896-1909, 1910.
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Elektrische und Maschinelle Betriebe, (Leipzig). 1-date, 1898-date.
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———— Bihang. All before 1828, 1829-1836, 1838-1867, 1869-1899.
———— Register. 1817-1890.
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Journal of Gas Lighting. 1-22, 51-52, 56, 57, 62-63, 93, 96, 99-108, 1850-1909.
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Neueste Erfindungen und Erfahrungen. 1-date, 1874-date.
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Petroleum Review, London. 1-25, 1889-1911.
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Schiffbau. 1-9, 1899-1908.
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Société Industrielle de Mulhouse. 1-71, 1828-1901.
Sozial Technik. 1-6, 1902-1907.
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# OFFICERS AND BOARD OF DIRECTORS, 1913-1914

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| | RALPH D. MERSHON, 1912-13. |

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**INTERNATIONAL ELECTRICAL CONGRESS, SAN FRANCISCO, 1915.**

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| **Baltimore**.....Dec. 16, '04 | J. B. Whitehead. | L. M. Potts, Industrial Building, Baltimore, Md. |
| **Boston**.....Feb. 13, '03 | Harold Pender | Harry F. Thomson, Massachusetts Institute of Techno'ogy, |
| **Chicago**..... 1893 | D. W. Roper. | E. W. Allen, 1028 Monadnock Building, Chicago, Ill. |
| **Cleveland**.....Sept. 27, '07 | J. C. Lincoln. | R. E. Scovel, 1663 East 86th Street, Cleveland, Ohio. |
| **Detroit-Ann Arbor**.Jan. 13, '11 | A. R. Sawyer. | Ray K. Holland, Cornwell Building, Ann Arbor, Mich. |
| **Fort Wayne**.....Aug. 14, '08 | T. W. Behan. | P. H. Haselton, Fort Wayne Electric Works Pt. Wayne, Ind. |
| **Indianapolis-Lafayette**.Jan. 12, '12 | O. S. More. | G. B. Schley, 908 Hume-Mansur Building, Indianapolis, Ind |
| **Ithaca**.....Oct. 15, '02 | E. L. Nichols. | George S. Macomber, Cornell University, Ithaca, N. Y. |
| **Los Angeles**.....May 19, '08 | E. R. Northmore. | C. G. Pyle, 914 Hibernian Bldg., Los Angeles, Cal. |
| **Lynn**.....Aug. 22, '11 | E. R. Berry. | J. A. McManus, Jr., General Electric Co., Lynn, Mass. |
| **Madison**.....Jan. 8, '09 | Edward Bennett. | F. A. Kartak, Univ. of Wisconsin, Madison, Wis. |
| **Mexico**.....Dec. 13, '07 | Norman Rowe. | James Carson, Mexican Light and Power Company, Mexico City, Mexico. |
| **Milwaukee**.....Feb. 11, '10 | L. E. Bogen. | L. P. Coulter, 2500 Chestnut Street, Milwaukee, Wis. |
| **Minnesota**.....Apr. 7, '02 | W. T. Ryan. | Fred G. Dustin, 9 South Fifth St., Minneapolis, Minn. |
| **Panama**.....Oct. 10, '13 | Edward Schildhauer. | W. R. McCann, Isthmian Canal Commission, Culebra, Canal Zone. |
| **Philadelphia**.....Feb. 18, '03 | A. R. Cheyney. | H. F. Sanville, 1326 Chestnut St., Philadelphia, Pa. |
| **Pittsburgh**.....Oct. 13, '02 | A. M. Dudley. | E. R. Spencer, 814 Frick Building, Pittsburgh, Pa. |
| **Pittsfield**.....Mar. 25, '04 | J. J. Frank. | G. W. Wade, General Electric Company, Pittsfield, Mass. |
| **Portland, Ore**.....May 18, '09 | G. P. Nock. | R. F. Monges, G. E. Co., Electric Building, Portland, Ore. |
| **St. Louis**..... ...Jan. 14, '03 | F. J. Bullivant. | A. McR. Harrelson, Emerson Electric Mfg. Co., St. Louis, Mo. |
| **San Francisco**...Dec. 23, '04 | A. H. Griswold. | A. G. Jones, 819 Rialto Building, San Francisco, Cal. |
| **Schenectady**.....Jan. 26, '03 | George H. Hill. | John R. Hewett, Gen. Elec. Co., Schenectady, N. Y. |
| **Seattle**.....Jan. 19, '04 | S. C. Lindsay. | E. A. Loew, University of Washington, Seattle, Wash. |
| **Spokane**.....Feb. 14, '13 | J. B. Fisken. | H. B. Peirce, Box 1436, Spokane, Wash. |
| **Toledo**.....June 3, '07 | George E. Kirk. | Max Neuber, Cohen, Freidlander & Martin, Toledo, O. |
| **Toronto**.....Sept. 30, '03 | D. H. McDougall. | H. T. Case, Continental Life Bldg., Toronto, Ont. |
| **Urbana**.....Nov. 25, '02 | Morgan Brooks. | I. W. Fisk, University of Illinois, Urbana, Ill. |
| **Vancouver**.....Aug. 22, '11 | E. M. Breed. | L. G. Robinson, 1003 Holden Building, Vancouver, B. C. |
| **Washington, D.C.**.Apr. 9, '03 | H. C. Eddy | C. B. Mirick, 1330 New York Avenue, N.W. Washington, D. C. |

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| **Agricultural and Mechanical College of Texas**.....Nov. 12, '09 | D. B. Pickens. | E. C. Rack, A. & M. College, College Station, Tex. |
| **Arkansas, Univ. of**.....Mar. 25, '04 | S. S. McGill. | M. B. Roys, Univ. of Arkansas, Fayetteville, Ark. |
| **Armour Institute**.....Feb. 26, '04 | E. L. Nelson. | T. C. Bolton, Armour Inst. Tech., Chicago, Ill. |
| **Bucknell University**.....May 17,'10 | F. O. Schnure. | J. M. Hillman, Bucknell University, Lewisburg, Pa. |
| **California, Univ. of**.....Feb. 9, '12 | L. R. Chilcote. | E. S. Middaugh, University of California, Berkeley, Cal. |
| **Cincinnati, Univ. of**.....Apr. 10, '08 | Mark Harned | A. C. Perry, University of Cincinnati, Cincinnati, O. |
| **Clemson Agricultural College**.....Nov. 8, '12 | F. J. Jervey. | F. H. McDonald, Clemson College, S. C. |
| **Colorado State Agricultural College**.....Feb. 11, '10 | L. M. Klinefelter. | R. K. Havighorst. Colorado State Agricultural College, Fort Collins, Colo. |
| **Colorado, Univ. of**.....Dec. 16, 04 | Philip S. Borden. | Charles S. Miller University of Colorado, Boulder, Colo. |
| **Highland Park College**..Oct. 11, '12 | E. B. Williams, | Ralph R. Chatterton, Highland Park College, Des Moines, Iowa. |
| **Iowa State College**.....Apr. 15, '03 | Earle G. Nichols. | F. A. Robbins, Iowa State College, Ames, Iowa. |
| **Iowa, Univ. of**.....May. 18, '09 | J. H. Scanlon. | A. H. Ford, University of Iowa, Iowa City, Ia. |
| **Kansas State Agr. Col**...Jan. 10, '08 | L. O'Brien. | W. C. Lane Kansas State Agric. Col., Manhattan, Kan. |
| **Kansas, Univ. of**.....Mar. 18, '08 | H. C. Hansen. | L. M. Bocker, Univ. of Kansas, Lawrence, Kansas. |
| **Kentucky State Univ. of**.Oct. 14, '10 | H. B. Hedges. | H. Tyler Watts, 315 East Maxwell Street, Lexington, Ky. |
| **Lafayette College**.....Apr. 5, '12 | R. McManigal. | W. J. English, Jr., Lafayette College, Easton, Pa. |
| **Lehigh University**.....Oct. 15, '02 | N. F. Matheson. | F. C. Brockman, Lehigh University, S. Bethlehem, Pa. |
| **Lewis Institute**.....Nov. 8, '07 | A. H. Pensholt, | Fred A. Rogers, Lewis Institute, Chicago, Ill. |
| **Maine, Univ. of**.....Dec. 26, '06 | C. M. Kelley. | E. L. Getchell, University of Maine, Orono, Maine. |
| **Michigan, Univ. of**.....Mar. 25, '04 | P. H. Evans. | E. T. Anderson, 608 Mary Court, Ann Arbor, Mich. |
| **Missouri, Univ. of**.....Jan. 10, '03 | E. W. Kellogg | K. Atkinson University of Missouri, Columbia, Mo. |
| **Montana State Col**.....May 21, '07 | John M. Fiske. | J. A. Thaler, Montana State College, Bozeman, Mont. |

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| **Nebraska, Univ. of**.....Apr. 10, '08 | Olin J. Ferguson. | V. L. Hollister, Station A, Lincoln, Nebraska |
| **New Hampshire Col.**.....Feb. 19, '09 | | |
| **North Carolina Col. of Agr. and Mech. Arts**.....Feb. 11, '10 | Wm.H.Browne,Jr. | James Fontaine, West Raleigh, N. C. |
| **Ohio Northern Univ**.....Feb. 9, '12 | George E. Boesger | Harry Restofski, Ohio Northern University, Ada, Ohio. |
| **Ohio State Univ.**.....Dec. 20, '02 | L. R. Yeager. | John M. Strait, Ohio State Univ., Columbus, Ohio. |
| **Oklahoma Agricultural and Mech. Col.**.....Oct. 13, '11 | A. P. Little. | Quentin Graham, 118 Husband St., Stillwater, Okla. |
| **Oklahoma, Univ. of**.....Oct. 11, '12 | R. D. Evans. | L. J. Hibbard, Univ. of Oklahoma, Norman, Okla. |
| **Oregon Agr. Col.**.....Mar. 24, '08 | A. O. Manigold. | I. L. Olmstead, Oregon Agric. Col., Corvallis, Ore. |
| **Oregon, Univ. of**.....Nov. 11, '10 | C. R. Reid. | C. H. Van Duyn, Univ. of Oregon, Eugene, Oregon. |
| **Penn State College**.....Dec. 20, '02 | A. D. Shultz, | A. T. McNeile, State College, Pa. |
| **Pittsburgh, University of**.Feb. 26, '14 | B. E. O'Hagan | George Hickman, University of Pittsburgh, Pittsburgh, Pa. |
| **Purdue Univ.**.....Jan. 26, '03 | C. F. Harding. | A. N. Topping, Purdue University, Lafayette, Ind. |
| **Rensselaer Poly. Inst.**....Nov. 12, '09 | W. J. Williams, | H. F. Wilson Rensselaer Poly. Institute, Troy, N. Y. |
| **Rose Polytechnic Inst.**....Nov. 10, '11 | Charles P. Harris. | Claude A. Lyon, 1331 Liberty Avenue, Terre Haute, Ind. |
| **Rhode Island State Col.**.Mar. 14, '13 | W. C. Miller. | P. M. Randall, Jr., Rhode Island State College, Kingston, R. I. |
| **Stanford Univ.**.....Dec. 13, '07 | G. L. Beaver. | H. J. Scholz, Stanford University, Cal. |
| **Syracuse Univ.**.....Feb. 24, '05 | W. P. Graham. | R. A. Porter, Syracuse University, Syracuse, N. Y. |
| **Texas, Univ. of**.....Feb. 14, '08 | Joseph W.Ramsey, | J. A. Correll. University of Texas, Austin, Tex. |
| **Throop College of Technology**.....Oct. 14, '10 | W. L. Newton, | A. W. Wells, Throop Poly. Institute, Pasadena, Cal. |
| **Virginia, Univ. of**.....Feb. 9, '12 | Walter S. Rodman | H. Anderson, Jr., 1022 West Main St., Charlottesville, Va. |
| **Wash., State Col. of**....Dec. 13, '07 | M. K. Akers. | H. V. Carpenter, State Coll. of Wash., Pullman, Wash. |
| **Washington Univ.**.....Feb. 6, '04 | R. D. Duncan, Jr. | C. C. Hardy, Washington University, St. Louis, Mo. |
| **Washington, Univ. of**...Dec. 13, '12 | H. W. McRobbie. | B. B. Bessesen, Univ. of Washington, Seattle, Wash. |
| **Worcester Poly. Inst.**....Mar. 25, '04 | Frank Aiken | A. B. R. Prouty, Worcester Poly. Inst., Worcester, Mass. |
| **Yale University**.....Oct. 03, 10 | F. M. Doolittle | W. L. Kenly, New Haven, Conn. |

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of

# Electrical Engineers

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*To be presented at the 290th Meeting of the American Institute of Electrical Engineers, New York, January 9, 1914.*

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*(Subject to final revision for the Transactions.)*

# SOURCES OF DIRECT CURRENT FOR ELECTRO-CHEMICAL PROCESSES

BY F. D. NEWBURY

ABSTRACT OF PAPER

The problem involved in producing direct current for electrochemical processes is outlined, and the difficulties are pointedout.

Of the methods of power supply using steam turbines that are available, it is shown that:

(a) Direct-connected d-c. turbo-generators are available only in relatively small units, and cannot be designed as conservatively from the commutation standpoint as is desirable.

(d) Unipolar generators driven by turbines have proven unsatisfactory on account of current collection difficulties.

(c) The standard medium-speed d-c. generator connected to a high-speed turbine through gearing affords a satisfactory unit.

(d) The combined a-c. turbo-generator and converter unit probably affords the best all-around method. It is economical, reliable and flexible. Its particular fields of application are where large units and long transmissions are required.

In waterpower plants, direct-connected d-c. generators and a-c. generators with converters are available. The combined a-c.-d-c. equipment is usually the most reliable and economical.

With reciprocating engine units, there is no reason for considering other methods than the direct-connected slow-speed generator.

THE ELECTRICAL power problem involved in all commercially important electrochemical processes is the production of very large amounts of direct current energy at comparatively low voltages. Single circuits often require as much as 10,000 amperes, and in electrolytic processes the voltage is rarely more than 250 volts. The present paper will briefly outline the problem, list the various methods of obtaining the required electrical energy and compare these methods from the standpoints of efficiency, first cost and reliability in operation.

The electrical problem is intimately connected with the available prime movers and their advantageous operating speeds. In modern installations, steam turbines and water wheels with their relatively high speeds are of major importance. Reciprocating steam engines are of importance mainly in combination with low pressure turbines. Up to the present time, gas and oil engines have had little or no application in modern electrochemical plants, but the present rapid development of



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the Diesel engine abroad may make its influence felt in the near future.

The design of direct-current machinery, either generators or rotary converters, of sufficient current capacity for electrochemical work, is a problem of considerable inherent difficulty because of the large currents involved, the high speeds of the preferred prime movers, and the continuous full load service required. In some cases, as in a-c. turbo-generators, the low voltage involved may become a serious limitation in design aside from its association with the large amperage.

The large currents and high speeds are closely associated and may be discussed together as the commutation problem.

## The Commutation Problem.

In direct-current generators and synchronous converters the *speed* and the permissible *number of poles* bears a certain relationship,the product of which, in terms of revolutions per second and pairs of poles, is the *frequency*. In synchronous converters this is, of course, a rigid relationship due to their synchronous operation. In direct-current generators, the frequency is commonly lost sight of but at the higher outputs and higher speeds under consideration it is practically as important a limitation, as in synchronous converters. The *current output* in commutating machines is proportional to the number of parallel circuits in the armature which in turn is equal to the number of poles. The tendency, therefore, is to increase the number of poles indefinitely as the required current output is increased. But this indefinite increase is limited, to mention only the most important factors, by the number of current collecting brush arms that can be placed around the commutator and the number of commutator bars that can be placed between brushes without exceeding safe commutator peripheral speeds. If conservative design limits are not to be exceeded, it is necessary to keep the frequency within 60 cycles and desirable to keep it within 50 cycles.

With the maximum number of parallel circuits and poles that can be used, the total current output is then limited by the permissible length of commutator. At the higher commutator speeds required by the frequencies usual with the d-c. generators under consideration, 800 amperes per brush arm is as high as should be considered under the continuous service required by electrochemical processes. Lower values are commonly used in

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60-cycle synchronous converters and higher values are permissible in 25-cycle converters, the peripheral speeds being respectively higher and lower. Uniformly higher values can be safely used for the intermittent service commonly experienced in industrial plants and central stations. Higher values can also be used in very low voltage machines using metal instead of carbon brushes.

With these none too conservative limits of 50 cycles and 800 amperes per brush arm, the following maximum current outputs result for 250-volt direct-current generators for the range of speeds commonly used:

| Prime mover and generator speed | Poles | Frequency | Amperes | Kw. at 250 volts |
|---|---|---|---|---|
| 1,800–1,500 | 4 | 60–50 | 1,600 | 400 |
| 500 | 12 | 50 | 4,800 | 1,200 |
| 400 | 16 | 53 | 6,400 | 1,600 |
| 300 | 20 | 50 | 8,000 | 2,000 |
| 250 | 24 | 50 | 9,600 | 2,400 |
| 200 | 30 | 50 | 12,000 | 3,000 |
| 175 | 34 | 50 | 13,600 | 3,400 |
| 150 | 40 | 50 | 16,000 | 4,000 |

Larger outputs than those listed have in some instances been built at certain speeds but only at the expense of reliability in operation. This is particularly true of direct-connected direct-current turbo-generators.

Double commutator generators if used would double the above ampere and kilowatt limits but difficulties inherent in parallel operation of the circuits from two commutators connected to the same winding have, after several unfortunate attempts, caused this construction to be abandoned for large machines where conservative practise has been followed.

It is evident from the above discussion that the major difficulties in building generators and synchronous converters for large currents center in the mechanical design of the commutator. The peripheral speed is pushed to the highest limit to obtain room for as many poles as possible; the length of commutator face is made as long as possible to increase the permissible current per circuit to the limit.

Three constructions have been developed and are in more or less general use to meet these severe conditions.

(a) A modification of the ordinary V-ring construction involving an additional auxiliary V-ring at the outer end of the commutator.

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(b) A modification of the ordinary V-ring construction involving a shrink midway between the two ends of the commutator bars.

(c) A simple shrink ring construction involving more shrink rings, depending on the length of the commutator.

The so-called three V-ring type retains all the advantages from the repair standpoint of the simpler two V-ring type. The combined V-ring shrink ring type has the disadvantages from a repair standpoint inherent in the simple shrink type. These two types are comparable in their range of application. Such commutators have been built with 20 to 25-in. (50.8 to 63.5-cm.) face and 5500 ft. (1676 m.) per minute peripheral speed. The simple shrink ring type obviously does not permit of easy repair and is limited to comparatively small commutator diameters. It is, however, the strongest construction available for smaller diameter commutators and is necessarily used for direct-connected turbo units.

Improvements in commutator design and construction during the past four or five years have been largely instrumental in improving the operation and extending the permissible output of the generators and synchronous converters under consideration.

A word in regard to the operation of machines having long high-speed commutators is not out of place. Such commutators built up in part, as they are, of more or less compressible insulating material, require a period of " seasoning " and adjustment before they will operate without further change in shape. A certain amount of such seasoning occurs during the manufacture and test of the machine (where testing is possible), but it is very seldom that additional grinding and tightening is not necessary after installation.

## The Distribution Problem

Energy in the form of heavy currents at comparatively low voltages as used in electrochemical work is not efficiently portable. It must be used substantially where it is generated. Very heavy busbar structures, expensive both in first cost and in energy loss, are necessary to carry the large currents involved, from the generator to the point at which it is used, and for distance more than a few hundred feet the cost becomes prohibitive. For transmission distances of 1000 ft. (304.8 m.) or more, it is usually necessary to consider transmission at a higher voltage. This introduces the alternating-current gen-

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erator and synchronous converter combination of power supply. The relative location of power station and the pots or tanks where the current is used has, therefore, an important bearing on the choice of a power system. This will be referred to again in detail in discussing water power installations.

## Voltage Variation

Electrochemical plants usually require some means of adjustment of the voltage in order to maintain constant current under the varying circuit conditions incident to operation. With direct-current generators this is readily obtained by simple field current control, a single generator usually supplying a single series of tanks. With synchronous converters, if the required range is not more than 5 per cent, it can also be obtained by adjustment of the field current, assuming sufficient reactance to exist in the alternating-current circuit. If a greater range of voltage variation is required, several methods are available, the one commonly preferred at the present time involving the addition of a small alternating-current generator to the synchronous converter unit, this generator acting as a synchronous booster. In both generators and converters, the performance under the wide range of voltage sometimes required has been greatly improved, in recent designs, by properly proportioned commutating poles.

## Continuity of Service

A feature of electrochemical load that has an important bearing on the satisfactory performance of the equipment is the requirement for steady full-load operation for long periods without shutdown. Many commutating machines that will operate with entire satisfaction on a fluctuating railway or lighting load will fail utterly on a continuous load of no greater value than the average load in the former case. The fluctuating load affords periods of light load during which the commutator and brushes can clean and polish themselves and the daily shutdowns permit the correction of incipient troubles. It is for this reason more than any other that serious trouble has been experienced in so many instances with commutating machines in electrochemical plants. For this reason alone commutating machines intended for operation in such plants should be of the most substantial and of the simplest type and should be designed, particularly from the standpoint of commutation, well within conservative limits.

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The general problem having been stated, the various methods of meeting the required conditions will be considered.

## Steam Turbine-Driven Units

Four arrangements involving steam turbine prime movers have been more or less successfully operated:

(a) Direct-connected commutator-type direct-current generators.

(b) Direct-connected unipolar-type direct-current generators.

(c) Gear-connected commutator-type direct-current generators.

(d) Direct-connected alternating-current generator with synchronous converter.

(*a*) Direct-connected, direct-current turbo-generators are limited to relatively small current ratings due to the very high speed necessary if reasonable turbine economy is to be obtained, and for such sizes as can be built, suitable for electrochemical work, conservative design limits must be exceeded. For this reason it is almost impossible to build direct-connected units that will be generally satisfactory under the severe operating conditions inherent in electrochemical works. The efficiency of the direct-current turbo-generator is low due to the high speed and frequency; that of the turbine is low due to the speed which, while high from the standpoint of the generator, is low from the standpoint of best turbine performance. The trend of development, both in this country and in Europe, where the most work with direct-connected direct-current units has been done, is away from direct-connected units.

(*b*) Since the difficulties in the design of direct-current generators for electrochemical work have been mainly associated with the commutator, a generator from which commutation has been eliminated would seem to offer a way out of all troubles. In the unipolar type, commutation is eliminated by the employment of unipolar flux, that is, flux of one polarity external to the armature. It is only necessary to collect the generated direct-current from the two ends of the armature by means of collector rings and brushes as commonly employed in alternating-current generators and synchronous converters. But it has required only two or three attempts with large units to show that, with the increase in current and speed desired, the simple process of current collection becomes a more difficult problem

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than commutation at the lower speeds available with alternative methods. The only unipolar generator large enough to be considered for electrochemical power supply now in commercial operation is the 2000-kilowatt, 250-volt, 8000-ampere 1200-rev. per min. unit described in a paper before this Institute.* This paper also gives in detail the difficulties encountered and overcome before this unit could be operated with reasonable maintenance cost. Due to the low core loss and windage loss of this type, the efficiency is relatively high. The first cost and maintenance cost, however, are also high.

(*c*) With the development, during the past three years, of a satisfactory gear for the transmission of large powers, the direct production of large currents with steam turbine prime movers has been placed on a much more satisfactory footing. This gearing is usually of the double helical type with the pinion mounted in a floating frame so as to equalize the tooth pressures in spite of the long face necessary. Obviously with an efficient and satisfactory gear available, the speeds of the turbine and the generator can be selected within fairly wide limits to suit the conflicting requirements of the prime mover and generator. As a matter of fact, generators which have been supplied for connection to turbines through gearing have been of the same speed and design as generators of the same rating driven by induction or synchronous motors in motor-generator sets. For example, such ratings for 250 volts would be 1000 kilowatts at 500 rev. per min., 1500 kilowatts at 360 rev. per min.; 2000 kilowatts at 300 rev. per min., and 3000 kilowatts at 180 rev. per min., which are all within the limiting ratings and speeds previously given. These units may, therefore, be designed as conservatively as similar generators used in motor-generator sets with relatively high efficiency and low cost. Such units have been in service for several years and have amply proven their dependability. Two large units of 3750 kilowatts, the turbine operating at 1800 rev. per min., and the generator at 180 rev. per min., have been supplied for lighting service.

(*d*) Another satisfactory means for obtaining the required direct current is afforded by turbine-driven alternating-current generators to which synchronous converters are electrically connected. The alternating-current generators may be of the usual synchronous type or of the induction type. This method has been used in a number of copper refining plants, and was

* *Development of a Successful Direct-Current* 2000-*kw. Unipolar Generator*, B. G. Lamme, PROCEEDINGS, A. I. E. E., June, 1912.

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used in industrial plants generally prior to the development of the geared unit. While it is lower in cost than either the direct-connected or unipolar types of generators and higher in efficiency than the former, it is somewhat inferior to the gear-connected unit, except when the unit becomes so large that 3600 rev. per min. turbines cannot be used in the geared unit. This method possesses obvious advantages in flexibility of plant arrangement. For plants in which the transmission distance is short enough, the generator can be designed for the required converter voltage and the converter connected directly to the generator terminals. Where, however, distances are greater, the generator can be wound for a higher voltage and step-down transformers installed with the converters at the electrolytic tanks.

Synchronous converters have been used instead of motor-generator sets primarily because of their higher efficiency. Considering the most unfavorable conditions from the standpoint of the synchronous converter, that is, a 60-cycle synchronous booster converter with transformers, the efficiency of a 1000 kilowatt, 250-volt, synchronous converter outfit would be, at least, 92 per cent, while the efficiency of an equivalent motor-generator set without transformers would rarely be higher than 88 per cent. Without transformers, without the boosters (where large variations in voltage are not required) and with a 25-cycle system, the comparison would be still more favorable to the synchronous converter.

If it is necessary to entirely separate, electrically, the different circuits, each consisting of a synchronous converter and series of tanks, this can be done as effectively by the use of transformers in connection with the converters as by the use of separate generators in motor-generator sets.

If transformers are necessary, the combined cost of the converter and transformer will be substantially the same as that of the motor-generator set.

The inherent advantages of the induction type generator for this service have been pointed out in a paper before the Institute* in which a specific application to electrolytic work was described. The stators of the synchronous and induction generators are substantially the same; the difference between them lies in the rotors. The rotor of the induction generator consists of a simple winding formed of bars short-circuited by end rings as in the more familiar induction motor. As in the

*_The Non-Synchronous Generator in Central Station and Other Work_, W. L. Waters, TRANSACTIONS, A. I. E. E., Vol XXVII, p. 157.

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motor, this winding need not be insulated from the core, and there are no collector rings and brushes which, at turbine speeds, require some care and attention. While, however, the induction type rotor is inherently simpler than the synchronous generator rotor, so much more development work has been done with the latter type that, as actually constructed, the synchronous rotor is, if anything, more reliable in operation than the rotor of the induction generator. The exciting or magnetizing current of the induction generator must be supplied from the synchronous converter so that the converter is under the handicap of operation at a power factor lower than unity. This handicap may become serious if it is desired to increase the voltage above that originally contemplated. The voltage of the synchronous generator on the other hand is very simply controlled by changes in its exciting current, so that in this respect the combined alternating-current generator-synchronous converter unit is on a par with the direct-current generator. For these reasons the induction generator has not been extensively applied.

The comparative efficiency of the various methods just described, based on a 2000-kilowatt, 250-volt unit are given in the following table:

| | Apparatus | Efficiency |
|---|---|---|
| (a) | Direct connected commutator type generator, three 750-kilowatt, 1500 rev. per min. | 89 |
| (b) | Direct connected unipolar type generator, 2000-kilowatt, 12,000 rev. per min. | 92 |
| (c) | Gear connected generator, | |
| | Gear 3,600-300 rev. per min. | 98 |
| | Generator 2,000 kilowatts, 300 rev. per min. | 93.5 |
| | Combined | 91.6 |
| (d) | Alternating-current generator-converter set | |
| | A-c. generator, 2,000-kilowatts, 3,600 rev. per min. | 94.5 |
| | Cables | 99.5 |
| | Synchronous converter, 2,000 kilowatts, 360 rev per min. | 96 |
| | Combined | 90.2 |

In considering these efficiencies, the lower economies of the lower speed turbines for (*a*) and (*b*), and for (*c*) in larger sizes, should not be lost sight of.

## Waterwheel-driven Units

With waterwheel-driven units, the choice lies between direct-connected direct-current generators or direct-connected alternating-current generators and synchronous converters. In very few plants can waterwheel generators be located near enough to the electrochemical plant to justify the installation of direct-connected direct-current generators, in view of the

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expensive structure required for the transmission of the heavy currents. The various questions involved in such an installation can best be brought out by a comparison of the d-c. and a-c.-d-c. installations in a specific instance.

For this purpose a plant having an ultimate capacity of 120,000 h.p. with a water power having a 250-ft. (76.2-m.) head has been chosen. The largest direct-current units that could be even considered are 5000-kilowatt, 250-volt operating at a speed of 170 rev. per min. It will be noted that this current rating in proportion to the speed is higher than previously given as a conservative rating. Nineteen such units would be required and with a diameter of approximately 25 ft. (7.6 m.) these generators would require a power house approximately 700 ft. (213.3 m.) long. Contrasted with the direct-current equipment, eight 12,500-kv-a., 277 rev. per min. 60-cycle generators could be used. These generators could be placed in a power house approximately 250 ft. (76 m.) long. In each case one spare unit is included. In further contrast with the direct-current units, the alternating-current units are well within conservative design limits, much larger generators at higher speeds having been built. With the direct-current units a lower speed has necessarily been chosen than would be most economical for the water wheels, consequently the water wheel efficiencies are lower for the direct-current plant than for the alternating-current plant. The comparative efficiencies with the two systems are shown in the following table:

COMPARATIVE EFFICIENCIES.

| | D-C. generation | A-C. generation and converters |
|---|---|---|
| Waterwheels | 80 per cent | 89 per cent |
| Generators | 95 | 96 |
| Transmission, assuming a distance of 2000 ft. (609 m.) | 92 | 99.5 |
| Step-down transformers | | 98.6 |
| Synchronous converters | | 96 |
| Low-tension wiring from step-down transformers to load (assuming 50 ft. 15.2 m.) | | 99.6 |
| Over-all efficiencies (from water to load) | 69.7 | 80.1 |

Ten per cent difference in efficiency would mean an appreciable difference in the investment cost and, therefore, in the cost of power even with a water power installation. In the present instance, assuming an investment cost of $60 per h.p., this difference would amount to three-quarters of a million dollars.

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The comparative costs of the two propositions based on the total cost of the direct-current system as 100 per cent are shown in the following table:

| | D-C. generation | A-C. generation and converters |
|---|---|---|
| 19-5,000-kilowatts 170-rev. per min. 250-volt d-c. generators with water wheels complete (one unit spare) approx. | 60 per cent | |
| 8-12,750 kilowatts 277 rev. per min., 11,000-volt 60-cycle a-c. generators with waterwheels complete (one unit a spare) approx. | | 38 per cent |
| Transmission [based on 90,000 kilowatts 250 volts for 2,000 ft. (609 m.) with copper at 10 ½ cts. per lb. (0.45 kg.) loss 8 per cent] approx. | 38 | 1 |
| 19-5250 kilowatts, three-phase, 60-cycles O. I. W. C. transformers 11,000 to 180 volts (one a spare unit) approx. | | 4½ |
| 19-5,000 kilowatts, six-phase, 250-volt d-c. synchronous converters with 10 per cent buck and 10 per cent boost (one a spare unit) approx., (Each unit consisting of two 2500-kilowatt converters) | | 29 |
| Low-tension wiring from step-down transformers to low [50 ft. (15.2m.) assumed] approx. | | 1 |
| Switching equipment, approx. | 2 | 7½ |
| Totals. | 100 | 81 |

The above costs do not include the cost of supports, anchors and insulation for the direct-current transmission line which, with the very heavy structure necessary, would be a considerable item.

Obviously with a smaller plant and, particularly, with a shorter transmission distance, the cost of the direct-current plant would be materially less. The efficiency, however, would not be greatly improved unless more efficient wheels could be used, and the drop in the transmission reduced by a material increase in the cost of this part of the plant. For example, for a plant of 60,000 h.p. instead of 120,000 h.p. and assuming 1000 ft. (304.8 m.) length and 5 per cent loss for the direct current transmission, the a-c.-d-c. plant would still have 8 per cent higher efficiency but its cost would be 10 per cent more than the direct current. Even on this basis the a-c.-d-c. plant would be more economical. Its flexibility is, moreover, an additional advantage of great importance.

These figures are well substantiated by the change in practise

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found desirable by one of the largest aluminum companies. All of the recent work done by this company has been with alternating-current generators and synchronous converters. A large installation involving nine 2500-kilowatt, 500-volt, 60-cycle synchronous converters is now being erected and a still larger installation involving 60-cycle machines of similar rating is in process of construction.

At the lower voltages more commonly involved in electrochemical work, a 60-cycle system has considerable advantage over a 25-cycle system. The higher frequency is an advantage from the standpoint of the turbine because of the higher available speeds; costs throughout the installation are less. In the synchronous converters the higher frequency is an advantage due to the larger number of poles and armature circuits for a given speed. At the higher voltages, that is, 500 to 700, sometimes used for the reduction of aluminum, there is a slight advantage from the standpoint of the synchronous converter design in the lower frequency. This, however, is not sufficient to overcome the other disadvantages incident to the lower frequency.

## Reciprocating Engine Units

While these units have very little application in modern plants, they should be mentioned to complete this survey. From the generator standpoint the lower speeds common with reciprocating units is a decided advantage, permitting as it does a large number of poles and armature circuits. On account of this fact there is no reason for considering other schemes than the simple direct-connected commutator-type direct-current generator. The efficiency of a 2000-kilowatt, 250-volt unit would be 94 per cent.

## Conclusion

From the many schemes proposed for the generation of direct current for electrochemical plants, two plans assuming steam turbine prime movers have decided advantages in efficiency and reliability and flexibility in operation. These are the gear-driven commutator-type generator where the distance between the power plant and the place of utilization is short, and the combined alternating-current generator and synchronous converter plant when this distance becomes too great for economical low-voltage transmission or the units become too large for economicla turbine speeds.

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*(Subject to final revision for the Transactions.)*

# INSTABILITY OF ELECTRIC CIRCUITS

BY CHARLES P. STEINMETZ

ABSTRACT OF PAPER

An outline of a theory and classification of instability in electric circuits is given, divided into three types:

1. The transients resulting from the readjustment of the stored energy to changed circuit conditions.
2. Unstable electrical equilibrium; that is, the condition in which the effect of a cause increases the cause. This is illustrated by the electric arc on constant potential, and the induction motor within certain speed ranges and loads.
3. Permanent instability resulting from a combination of circuit constants which can not co-exist. This is illustrated by the arcing ground on a transmission line, and by the hunting of synchronous converters, and the phenomena of continuous and cumulative oscillations. It is shown that such phenomena require an energy supply resulting from a lag of the effect behind the cause, or a hysteresis cycle, and frequently involve a frequency transformation.

The phenomenon of hunting of synchronous machines, and the mechanism of the transfer of the hunting energy from the supply power, then is treated explicitly, as an illustration of the general character of these phenomena.

DURING the earlier days of electrical engineering practically all theoretical investigations were limited to circuits in stable or stationary condition, and where phenomena of instability occurred, and made themselves felt as disturbances or troubles in electric circuits, they either remained not understood, or the theoretical study was limited to the specific phenomenon, as in the cases of lightning, dropping out of step of induction motors, hunting of synchronous machines, etc., or, as in the design of arc lamps and arc lighting machinery, the opinion prevailed that theoretical calculations were impossible and that design by trial only, based on practical experience, was feasible.

The first class of unstable phenomena, which was systematically investigated, was the transients, and even today it is questionable whether a systematic theoretical classification and investigation of the conditions of instability in electric circuits is yet feasible. Only a preliminary classification and discussion of such phenomena will be attempted in the following.



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Three main types of instability in electric systems may be distinguished:

1. The transients of readjustment to changed circuit conditions.

2. Unstable electrical equilibrium; that is, the condition in which the effect of a cause increases the cause.

3. Permanent instability resulting from a combination of circuit constants which cannot co-exist.

## (1) Transients

Transients are the phenomena which occur at the change of circuit conditions, when current, voltage, etc., readjust themselves from the values corresponding to the previous condition to the values corresponding to the new condition of the circuit. For instance, if a switch is closed, and thereby a load put on the circuit, the current cannot instantly increase to the value corresponding to the increased load, but some time elapses, during which the increase of the stored magnetic energy corresponding to the increased current, is brought about. Or, if a motor switch is closed, a period of acceleration intervenes before the flow of current becomes stationary, etc.

The characteristic of transients therefore is, as implied in the term, that they are of limited, and usually of very short duration, intervening between two periods of stable conditions.

Considerable theoretical work has been done, more or less systematically, on transients, and a great mass of information is thus available in the literature. However, to some extent, the transients of our theoretical literature, are still those of the "phantom circuit"; that is, a circuit in which the constants $r$, $L$, $C$, $g$, are assumed as constant. The effect of the variation of constants, as found more or less in actual circuits, viz., the change of $L$ with the current in circuits containing iron; the change of $C$ and $g$ with the voltage (corona, etc.); the change of $r$ and $g$ with the frequency, etc., has been studied to a limited extent only, and in specific cases.

In the application of the theory of transients to actual electric circuits, considerable judgment is thus often necessary to allow and correct for these "secondary" phenomena which are not included in the theoretical equations.

Especially deficient is our knowledge of the conditions under which the attenuation constant of a transient becomes zero or negative, and the transient thereby becomes permanent, or be-

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comes a cumulative surge, and the phenomenon thereby is taken out of group one and falls under group three or group two of unstable systems.

### (2) Unstable Electrical Equilibrium

If the effect brought about by a cause is such as to oppose or reduce the cause, the effect must limit itself and stability be finally reached. If, however, the effect brought about by a cause increases the cause, the effect continues with increasing intensity, that is, instability results.

This applies not to electrical phenomena alone, but equally to all other phenomena.

For instance, if in a motor, by increase of load, the torque becomes less than the load, the motor slows down. If now the decrease of speed of the motor increases the motor torque—as in a series motor—the decrease of speed stops at the speed at which the motor torque has become equal to the load. Thus, the decrease of speed limits itself, and a stable condition is restored at a lower speed. If, however, the decrease of speed of the motor decreases the motor torque—as in an induction motor below the maximum torque point—the decrease of the motor speed causes a still greater reduction of the motor torque below the load, and, therefore, a still greater slowing down of the motor, and thus with increasing rapidity the motor speed decreases until the motor stops; a condition of unstable equilibrium.

Such instability is usually the result of the system; that is, the combination of elements, but is not inherent in any of the elements. For example, in the above instance of the induction motor, while the part of the induction motor speed torque curve below the maximum torque is often called the "unstable branch", this is true only relatively. If, with the decrease of the speed of the motor due to an increased load, the load would also decrease, and if the load should decrease with the speed at a faster rate than the motor torque decreases, (fans, ship propellers), the decrease of speed would limit itself; that is, the condition would be stable.

To illustrate more fully, in Fig. 1 are shown the speed-torque curves of an induction motor for various values of constant impressed voltage, $e_1, e_2, e_3 \ldots e_8$.

With a load requiring the same constant torque at all speeds, $A$, in Fig. 1, the motor could not run at all at voltages $e_1$ and $e_2$.

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At voltages $e_7$ and $e_8$ the motor would start and run up to a speed near synchronism, where it is stable. At voltages $e_3$ to $e_6$ the motor torque equals the load at two speeds, $a_1$ and $a_2$, on the curve $e_4$. The higher one of these is stable, the lower unstable. From any speed above $a_2$ the motor speeds up to $a_1$. From any speed below $a_2$, it slows down to a standstill. All the speeds below that corresponding to the maximum torque point $c_0$ are unstable with this character of load and cannot

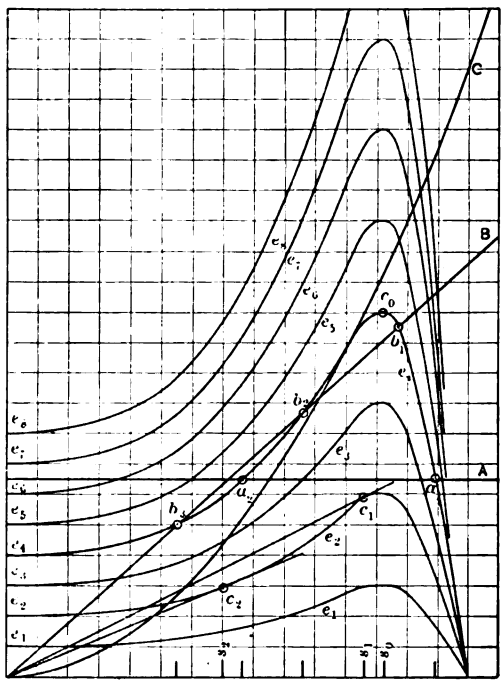


FIG. 1—SPEED-TORQUE CURVES OF INDUCTION MOTOR

persist, but the motor either accelerates and runs up to above $s_0$ or slows down to standstill.

With a load requiring a torque proportionate to the speed, $B$, in Fig. 1 (electric generator with constant field excitation and constant resistance of load), the motor always starts, but for voltages $e_1$ to $e_3$ never can run above a low speed (where the current is high and the efficiency and power factor low). For voltages of $e_5$ and above the motor starts and runs up to a speed near synchronism. For voltage $e_4$ three points exist, $b_1$, $b_2$, $b_3$,

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where the motor torque equals the load; $b_1$ and $b_3$ are stable, $b_2$ unstable. From below $b_2$ the motor slows down to $b_3$. From above $b_2$ it speeds up to $b_1$. The motor curve now has an unstable branch between the speeds $s_2$ and $s_1$ (corresponding to the two points of contact, $c_2$ and $c_1$, of the motor torque with tangents from the origin, which for the sake of clearness have been illustrated on curve $e_2$), and two stable branches below $s_2$ and above $s_1$.

With a load requiring a torque proportional to the square of the speed, $C$, in Fig. 1 (fan, ship propeller), unstability does not exist, but the conditions are always stable over the entire range of the speed torque curve of the motor, and the motor always starts and runs up to a definite speed, which is the only speed at which the motor can carry the particular load. With other shapes of motor torque curves—as those due to a drop of supply voltage with a decrease of speed—an unstable range may appear between two stable ranges, and in the case $C$ also.

Probably the most important case of unstable electrical equilibrium is afforded by circuits containing an arc. It is the determining feature in the design of arc lamps, circuits and machinery, and is possibly responsible for more disturbances in electric circuits than any other phenomenon.

The voltage consumed by an arc decreases with increase of current, as shown by curve $A$, in Fig. 2. If then the arc is operated from a supply circuit of constant voltage, $e_0$, Fig. 2, and $r$ is the resistance of this supply circuit outside of the arc, the voltage consumed by the resistance $r\,i$, is shown by $B$, in Fig. 2, and the total voltage of arc and resistance derived by adding $A$ and $B$ is given by $C$, in Fig. 2. As seen, two values of current exist, $i_1$ and $i_2$, at which the arc could operate in this circuit. The higher current $i_1$ is stable, the lower current $i_2$, is unstable, and the branch of the curve $C$ below the minimum point $i_0$ is unstable; that above $i_0$ is stable.

On a constant-current circuit the arc at atmospheric pressure is stable.

Inversely, with the mercury arc in a vacuum, as the quartz lamp, instability may appear under certain conditions on a constant current circuit, as the result of the relation of temperature and voltage. Increasing temperature increases the vapor pressure, and with it the voltage, and thus, on constant current, the power consumed by the vacuum arc. Increasing power consumption, however, increases the temperature, and thereby

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the voltage, and so on, and if the rate of temperature rise, due to increasing voltage, is greater than the rate of voltage rise due to increasing temperature, instability results, and the arc runs away; otherwise it is stable.

Similar phenomena, as shown by the arc, are exhibited by some solid conductors, which, in a certain temperature range, have a very high temperature coefficient; so-called "pyro-electrolytes". A typical volt-ampere curve of such a conductor is shown in Fig. 3. As seen, at voltage $e_0$ three values of current are possible, $i_1$, $i_2$, and $i_3$. Of these the low and the high ones

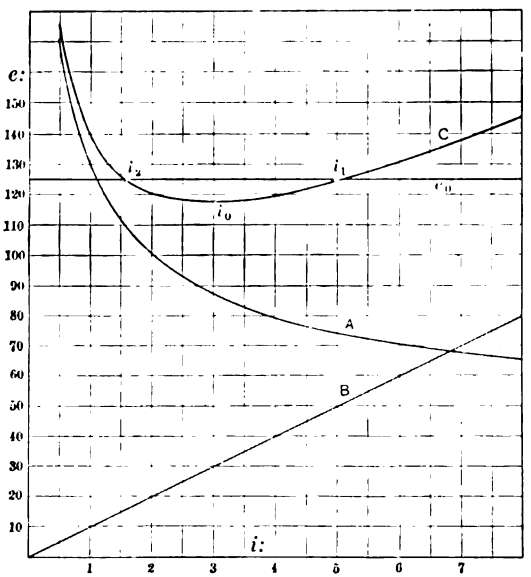


FIG. 2—VOLTAGE OF ARC

are stable, the intermediate one $i_2$ unstable, and so is the entire range between $i_0$ and $i_0'$, the maximum and the minimum of the volt-ampere characteristic.

The Nernst lamp glower is such a pyro-electrolyte, and its operating current is on the unstable branch of the characteristic, therefore a steadying resistance or reactance is required, just as with an arc on constant voltage supply. Most of these conductors are chemical compounds, and at higher currents, and thus temperatures, their conduction becomes electrolytic. However, some elementary substances, as boron and silicon, also belong to this class of conductors.

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### (3) Permanent Instability

If the constants of an electric circuit, as resistance, inductance, capacity, disruptive strength, impressed voltage, etc., have values which cannot co-exist, the circuit is unstable, and remains so as long as these constants remain unchanged. Such instability usually leads to phenomena which are more or less periodic or intermittent.

The nature of these phenomena of permanent instability is best shown by an example illustrated in Fig. 4. Let $A$ and $B$ be two conductors of an ungrounded high-potential transmission line, and $2e$ the voltage impressed between these two conductors. Let $C$ represent the ground.

The capacity of the conductors $A$ and $B$ against ground may

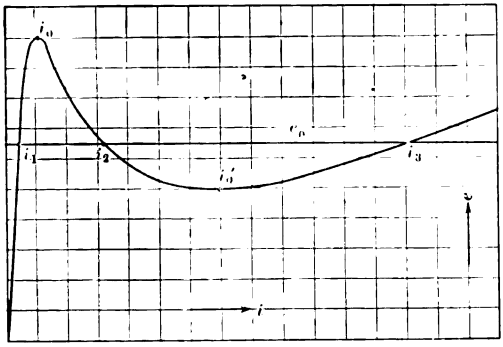

Fig. 3—Volt-Ampere Curve of "Pyro-Electrolyte"

then be represented diagrammatically by two condensers $C_1 = C_2$, and the voltages from the lines to ground by $e_1$ and $e_2$. In general, the two line capacities are equal: $C_1 = C_2$, and the two voltages to ground thus equal also: $e_1 = e_2 = e$ with a single-phase, and $= \frac{2e}{\sqrt{3}}$ with a three-phase line.

Assume now that a ground $P$ is brought near one of the lines $A$, but within the striking distance of the voltage $e$. A discharge then occurs over the conductor $P$. Such may occur by the puncture of a line insulator as is not infrequently the case. Let $r$ = resistance of the discharge path $P$. While without this discharge path, the voltage between $A$ and $C$ would be $e_1 = e$ (assuming a single-phase circuit) with a grounded conductor $P$ approaching line $A$ within striking distance of voltage $e$, a

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discharge occurs over $P$, forming an arc, and the circuit of the impressed voltage $2e$ now comprises the condenser $C_2$ in series to the multiple circuit of condenser $C_1$ and arc $P$, and the condenser $C_1$ rapidly discharges, voltage $e_1$ decreases, and the voltage $e_2$ increases. With a decrease of voltage $e_1$, the discharge current $i$ also decreases, and the voltage consumed by the discharge arc $e'$ increases until the two voltages, $e_1$ and $e'$, cross, as shown in the curve diagram of Fig. 4. At this moment the current $i$ in the arc vanishes, the arc ceases, and the shunt of the conden-

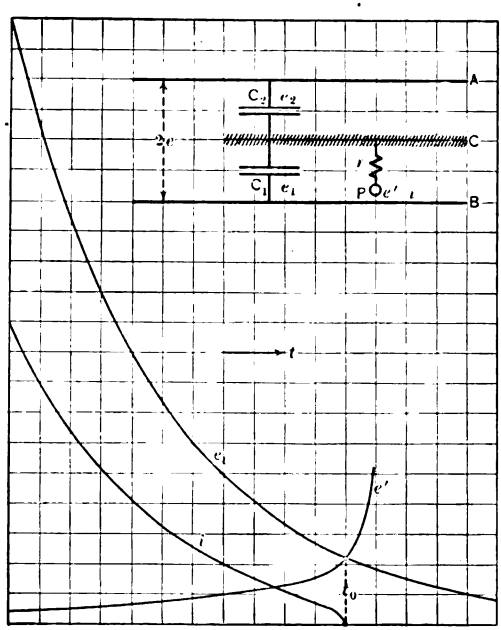


FIG. 4—ILLUSTRATING CONDITION OF PERMANENT INSTABILITY

ser $C_1$ formed by the discharge over $P$ thus ceases. The voltage $e_1$ then rises, $e_2$ decreases, and the two voltages tend toward equality, $e_1 = e_2 = e$. Before this point is reached, however, the voltage $e_1$ has passed the disruptive strength of the discharge gap $P$, the discharge by the arc over $P$ again starts, and the cycle thus repeats indefinitely.

In Fig. 4 are diagrammatically sketched voltage $e_1$ of condenser $C_1$, the voltage $e'$ consumed by the discharge arc over $P$, and the current $i$ of this arc, under the assumption that $r$ is sufficiently high to make the discharge non-oscillatory. If $r$ is small each of these successive discharges is an oscillation.

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Such an unstable circuit gives a continuous series of successive discharges, which are single impulses, as in Fig. 4, or more commonly are oscillations.

If the line conductors $A$ and $B$ in Fig. 4 have appreciable inductance, as is the case with transmission lines, in the charge of the condenser $C_1$, after it has been discharged by the arc over $P$, the voltage $e_1$ would rise beyond $e$, approaching $2e$, and the discharge would thus start over $P$, even if the disruptive strength of this gap is higher than $e$, provided that it is still below the voltage momentarily reached by the oscillatory charge of the line condenser $C_1$.

This combination of two transmission line conductors and the ground conductor $P$, approaching near line $A$ to a distance giving a striking voltage above $e$, but below the momentarily charging voltage of $C_1$, then constitutes a circuit which has two permanent conditions, one of stability and one of instability. If the voltage $2e$ is gradually applied, $e_1 = e_2 = e$, the condition is stable, as no discharge occurs over $P$. If, however, by some means, as a momentarily overvoltage, a discharge is once produced over the spark gap $P$, the unstable condition of the circuit persists in the form of successive and recurrent discharges.

The most interesting class in this group of unstable electric systems is the oscillations resulting sometimes from a change of circuit conditions (switching, change of load, etc.) which continue indefinitely with constant intensity, or which steadily increase in intensity, and may thus be called permanent and cumulative surges, hunting, etc. They may be considered as transients in which the attenuation constant is zero or negative.

In the transient resulting from a change of circuit conditions, the energy which represents the difference of stored energy of the circuit before and after the change of circuit conditions, is dissipated by the energy loss in the circuit. As energy losses always occur, the intensity of a true transient thus must always be a maximum at the beginning, and steadily decrease to zero or to a permanent condition. An oscillation of constant intensity or of increasing intensity thus is possible only by an energy supply to the oscillating system brought about by the oscillation. If this energy supply is equal to the energy dissipation, constancy of the phenomenon results. If the energy supply is greater than the energy dissipation, the oscillation is cumulative, and steadily increases until self-destruction of the

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system results, or the increasing energy loss becomes equal to the energy supply, and a stationary condition of oscillation results. The mechanism of this energy supply to an oscillating system from a source of energy differing in frequency from that of the oscillation, is still practically unknown, and very little investigating work has been done to clear up the phenomenon. It is not even generally understood that the phenomenon of a permanent or cumulative line surge involves an energy supply, or energy transformation, of a frequency equal to that of the oscillation.

Possibly the oldest and best known instance of such cumulative oscillations is the hunting of synchronous machines.

Cumulative oscillations between electro-magnetic and electrostatic energy have been observed by their destructive effects in high-voltage electric circuits, on transformers and other apparatus, and have been, in a number of instances where their frequency was sufficiently low, recorded by the oscillograph. They obviously are the most dangerous phenomena in high-voltage electric circuits. Relatively little exact knowledge exists of their origin. Usually, if not always, an arc somewhere in the system is instrumental in the energy supply which maintains the oscillation. In some instances, as in wireless telegraphy, they have found industrial application. A systematic theoretical investigation of these cumulative electrical oscillations probably is one of the most important problems before the electrical engineer today.

The general nature of these permanent and cumulative oscillations and their origin by oscillating energy supply, from the transient of a change of circuit condition, is best illustrated by the instance of the hunting of synchronous machines, and this may, therefore, be investigated somewhat more in detail.

Practically all theoretical study of the hunting of synchronous machines has been limited to the calculation of the frequency of the transient oscillation of the synchronous machine, at a change of load, frequency or voltage, at synchronizing, etc. However, this transient oscillation is harmless, and becomes dangerous only if the oscillation ceases to be transient, but becomes permanent and cumulative; and thus the most important problem in the study of hunting is the determination of the cause which converts the transient oscillation into a cumulative one; that is, the determination of the source of the energy, and the mechanism of its transfer to the oscillating system. To design

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synchronous machines so as to have no or very little tendency to hunting, obviously requires a knowledge of those characteristics of design which are instrumental in the energy transfer to the oscillating system, and thereby cause hunting, so as to avoid them and produce the greatest possible inherent stability.

If, in an induction motor running loaded, at constant speed, the load is suddenly decreased, the torque of the motor being in excess of the reduced load causes an acceleration, and the speed increases. As, in an induction motor, the torque is a function of the speed, the increase of speed decreases the torque, and thereby decreases the increase of speed until that speed is reached at which the motor torque has dropped to equality with the load, and thereupon acceleration and further increase of speed ceases, and the motor continues in operation at the constant higher speed. That is, the induction motor reacts on a decrease of load by an increase of speed, which is gradual and steady without any oscillation.

If, on a synchronous motor running loaded, the load is suddenly decreased, the beginning of the phenomenon is the same as in the induction motor; the excess of motor torque causes an acceleration, that is, an increase of speed. However, in the synchronous motor the torque is not a function of the speed, but in a stable condition, the speed must always be the same, synchronism, and the torque is a function of the relative position of the rotor to the impressed frequency. The increase of speed, due to the excess torque resulting from the decreased load, causes the rotor to run ahead of its previous relative position, and thereby decreases the torque until by means of increased speed, the motor has run ahead from the relative position corresponding to the previous load, to the relative position corresponding to the decreased load. Then the acceleration, and with it the increase of speed, stops. But the speed is higher than in the beginning, that is, is above synchronism, and the rotor continues to run ahead, the torque continues to decrease, is now below that required by the load, and the latter thus exerts a retarding force, decreases the speed, and brings it back to synchronism. But when synchronous speed is reached again the rotor is ahead of its proper position, and thus cannot carry its load, and it begins to slow down, until it is brought back into its proper position. At this position, however, the speed is now below synchronism, and the rotor thus continues to drop back, and the motor torque increases beyond the load,

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thereby accelerates again to synchronous speed, etc., and in this manner conditions of synchronous speed, with the rotor position behind or ahead of the position corresponding to the load, alternate with conditions of proper relative position of the rotor, but below or above synchronous speed; that is, an oscillation results which usually dies down at a rate depending on the energy losses resulting from the oscillation.

As seen, the characteristic of the synchronous machine is, that readjustment to a change of load requires a change of relative position of the rotor with regard to the impressed frequency without any change of speed, while a change of relative position can be accomplished only by a change of speed, and this results in an over-reaching in position and in speed; that is, in an oscillation.

Due to the energy losses caused by the oscillation, the successive swings decrease in amplitude, and the oscillation dies down. If, however, the torque which brings the rotor back from the position ahead or behind its normal position corresponding to the changed load (excess or deficiency of motor torque and of the torque required by the load) is greater than the torque which opposes the deviation of the rotor from its normal position, each swing tends to exceed the preceding one in amplitude, and if the energy losses are insufficient, the oscillation thus increases in amplitude and becomes cumulative; that is, hunting.

In Fig. 5 is shown diagramatically, as $p$, the change of the relative position of the rotor, from $p_1$ corresponding to the previous load to $p_2$ the position further forward corresponding to the decreased load: $v$ then shows the oscillation of speed corresponding to the oscillation of position.

The dotted curve, $w_1$, then shows the energy losses resulting from the oscillation of speed (hysteresis and eddies in the pole faces, currents in damper windings), that is, the damping power, assumed as proportional to the square of the speed.

If there is no lag of the synchronizing force behind the position displacement, the synchronizing force, that is, the force which tends to bring the rotor back from a position behind or ahead of the position corresponding to the load, would be—or may approximately be assumed as—proportional to the position displacement $p$, but with reverse sign: positive or accelerating when $p$ is negative or behind the normal position, negative or retarding when $p$ is ahead. The synchronizing power, that is,

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the power exerted by the machine to return to the normal position, then is derived by multiplying $-p$ by $v$, and is shown dotted as $w_2$ in Fig. 5. As seen, it is a double frequency alternation with zero as average.

The total resultant power or the resulting damping effect which restored stability, then is the sum of the synchronizing power $w_2$ and the damping power $w_1$, and is shown by the dotted curve $w$. As seen, under the assumption of Fig. 5, in this case a rapid damping occurs.

If the damping winding, which consumes a part or all the

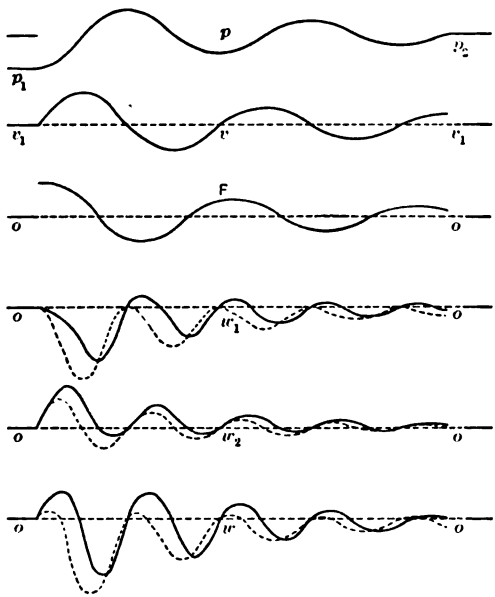


FIG. 5—OSCILLATIONS DUE TO CHANGE OF LOAD

power $w_1$, is inductive—and to a slight extent it always is—the current in the damping winding lags behind the e.m.f. induced in it by the oscillation, that is, lags behind the speed $v$, and the power $w_1$, or that part of it which is current times voltage, then ceases to be continuously negative or damping, but contains a positive period, and its average is greatly reduced, as shown by the drawn curve $w_1$, in Fig. 5; that is, inductivity of the damper winding is very harmful, and it is essential to design the damper winding as non-inductive as possible to give efficient damping.

With the change of position $p$, the current, and thus the arma-

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ture reaction, and with it the magnetic flux of the machine, changes. A flux change cannot be brought about instantly, as it represents energy stored, and as a result the magnetic flux of the machine does not exactly correspond with the position $p$, but lags behind it, and with it the synchronizing force $F$, as shown in Fig. 5, more or less, depending on the design of the machine.

The synchronizing power of the machine, $Fv$, in the case of a lagging synchronizing force $F$, is shown by the drawn curve $w_2$. As seen, the positive ranges of the oscillation are greater than the negative ones; that is, the average of the oscillating synchronizing power is positive, supplying energy to the oscillating system, which energy tends to increase the amplitude of the oscillation; in other words, tends to produce cumulative hunting.

The total resulting power, $w = w_1 + w_2$, under these conditions, is shown by the drawn curve $w$, in Fig. 5. As seen, its average is still negative or energy consuming, that is, the oscillation still dies out, and stability is finally reached, but the average value of $w$ in this case is so much less than in the case above discussed, that the dying out of the oscillation is much slower.

If now the damping power $w_1$ were still smaller, or the average synchronizing power $w_2$ greater, the average of $w$ would become positive, supplying energy to the oscillating system. In other words, the oscillation would increase and hunting result. That is, if the average synchronizing power resulting from the lag of the synchronizing force behind the position exceeds the average damping power, hunting results. The condition of stability of the synchronous machine is, that the average damping power exceeds the average synchronizing power, and the more this is the case, the more stable is the machine; that is, the more rapidly the transient oscillation of readjustment to changed circuit conditions dies out.

Or, if

$a$ = attenuation constant of the oscillating system,

$a < 0$ gives cumulative oscillation or hunting;

$a > 0$ gives stability.

Counting the time $t$ from the moment of maximum backward position of the rotor, that is, the moment at which the load on the machine is decreased, and assuming sinusoidal variation, and denoting

$$\phi = 2\pi f t = \omega t \qquad (1)$$

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where

$f$ = frequency of the oscillation. (2)

The relative position of the rotor then may be represented by

$$p = -p_0 \cdot \epsilon^{-a\phi} \cos \phi$$

where

$p_0 = p_2 - p_1$ = position difference of rotor resulting from change of load, (3)

$a$ = attenuation constant of oscillation (4)

The velocity difference from that of uniform rotation then is

$$v = \frac{dp}{dt} = \omega \frac{dp}{d\phi} = \omega p_0 \epsilon^{-a\phi} (\sin \phi + a \cos \phi) \quad (5)$$

Let

$$a = \tan \alpha; \quad 1 + a^2 = A^2 \quad (6)$$

hence

$$\sin \alpha = \frac{a}{A}; \quad \cos \alpha = \frac{1}{A} \quad (7)$$

it is

$$v = \omega p_0 A \epsilon^{-a\phi} \sin (\phi + \alpha) \quad (8)$$

Let

$\gamma$ = lag of damping currents behind e. m. f. induced in damper windings; (9)

the damping power is

$$w_1 = -c v v_r = -c \omega^2 p_0^2 A^2 \epsilon^{-2a\phi} \sin (\phi + \alpha) \sin (\phi + \alpha - \gamma) \quad (10)$$

where

$$c = \frac{w}{v^2} = \text{damping power per unit velocity} \quad (11)$$

Let

$\beta$ = lag of synchronizing force behind position displacement $p$, and (12)

$$\beta = \omega t_0 \quad (13)$$

where

$t_0$ = time lag of synchronizing force. (14)

The synchronizing force then is

$$F = b p_0 \epsilon^{-a\phi} \cos (\phi - \beta) \quad (15)$$

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where

$$b = \frac{F_0}{p_0} = \text{ratio of synchronizing force to position displacement, or specific synchronizing force.} \quad (16)$$

The synchronizing power then is

$$w_2 = Fv = b\,\omega\,p_0^2\,A\,\epsilon^{-2a\phi}\sin(\phi+\alpha)\cos(\phi-\beta) \quad (17)$$

The oscillating mechanical power is

$$w = \frac{d}{dt}\frac{mv^2}{2} = m\,\omega\,v\,\frac{dv}{d\phi}$$

$$= m\,\omega^3 p_0^2 A^2 \epsilon^{-2a\phi}\sin(\phi+\alpha)\{\cos(\phi+\alpha) - a\sin(\phi+\alpha)\} \quad (18)$$

where

$m$ = moving mass reduced to the radius, on which $p$ is measured. (19)

It is, however,

$$w_1 + w_2 - w = 0. \quad (20)$$

Hence, substituting (10), (17), (18) into (20) and canceling,

$$b\cos(\phi-\beta) - c\,\omega\,A\sin(\phi+\alpha-\gamma) - m\,\omega^2 A\cos(\phi+\alpha) + m\,\omega^2 A\,a\sin(\phi+\alpha) = 0 \quad (21)$$

This gives as the coefficients of $\cos\phi$ and $\sin\phi$ the equations

$$\left.\begin{aligned} b\cos\beta - c\,\omega A\sin(\alpha-\gamma) - m\,\omega^2 A\cos\alpha + m\,\omega^2 A a\sin\alpha = 0 \\ b\sin\beta - c\,\omega A\cos(\alpha-\gamma) + m\,\omega^2 A\sin\alpha + m\,\omega^2 A a\cos\alpha = 0 \end{aligned}\right\} \quad (22)$$

Substituting (6) and (7) and approximating from (13), for $\alpha$ as a small quantity,

$$\cos\beta = 1; \quad \sin\beta = \omega t_0 \quad (23)$$

gives

$$\left.\begin{aligned} b - c\,\omega(a\cos\gamma - \sin\gamma) - m\,\omega^2(1-a^2) &= 0 \\ bt_0 - c(\cos\gamma + a\sin\gamma) + 2m\,\omega\,a &= 0 \end{aligned}\right\} \quad (24)$$

This gives the values, neglecting smaller quantities,

$$a = \frac{c\cos\gamma - b\,t_0}{\sqrt{4mb - c^2\cos 2\gamma + b^2 t_0^2}} \quad (25)$$

$$\omega = \frac{1}{2m}\{\sqrt{4mb - c^2\cos 2\gamma + b^2 t_0^2} + c\sin\gamma\} \quad (26)$$

$$f = \frac{\omega}{2\pi} \quad (27)$$

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These equations (25) and (26) apply only for small values of $a$, but become inaccurate for larger values of $a$, that is, very rapid damping. However, the latter case is of lesser importance.

$$a = 0 \text{ gives}$$
$$b\, t_0 = c \cos \gamma$$

hence

$$\left.\begin{aligned} c &> \frac{b\, t_0}{\cos \gamma} \\ \text{or} \\ t_0 &> \frac{c \cos \gamma}{b} \end{aligned}\right\} \qquad (28)$$

is the condition of stability of the synchronous machine.

If

$$t_0 = 0$$
$$\gamma = 0$$

then

$$a = \frac{c}{\sqrt{4\, mb - c^2}}$$

$$\omega = \frac{\sqrt{4\, mb - c^2}}{2m}$$

and, if, also,

$$c = 0$$

$$\omega = \sqrt{\frac{b}{m}}$$

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## DISCUSSION ON "STANDARDIZATION OF METHOD FOR DETERMINING AND COMPARING POWER COSTS IN STEAM PLANTS". (STOTT AND GORSUCH), COOPERSTOWN, NEW YORK, JUNE 26, 1913. (SEE PROCEEDINGS FOR MAY, 1913).

*(Subject to final revision for the Transactions)*

**Henry Floy:** Turning to the last pages of the paper, it is a disappointment to find that the final formula, given on page 1130, in which one looks to find the solution of the problem discussed, omits a part of the "total cost" elements mentioned on page 1119. In fact the question may be fairly raised whether "General and Miscellaneous Administration Expenses" of one plant are capable of direct comparison with those of another plant upon the basis merely of output. These expenses really have little to do with the question of scientific perfection of design or efficiency of operation of a power plant. Proportioning such expenses to power costs in the relation of such costs to total costs, as mentioned on page 1116, may be unfair. This may be seen by considering the disproportionately large amount of the president's salary, for example, compared to his time or effort, that would be allotted to power cost, when based on the ratio of expense for fuel to the total expense. Perhaps a more equitable method of proportioning the general officers' salaries would be on the basis of letters found in office files relating to the different departments, or dividing auditing expenses in proportion to the vouchers passed for the various departments. Another omission from the formula presented is the failure to take into consideration for comparison, the substituted cost of water and its treatment for boiler and condensing purposes, which might be quite different with appreciable effect on power costs in the plants being compared.

Presumably the division of production and repair costs proposed, are along the lines of accounting established by the Public Service Commission of New York State, but pensions included in general expenses at foot of page 1102, are not in accordance with such classification. Neither is the item of interest included, as given among investments costs on page 1109. If variation from accepted rules of accounting is to be made, improvement in details should be expected. Why boiler insurance, for example, should be included as a part of repair costs and employees' insurance, with the attendant expenses, should be put in production costs, is not clear and is one of the apparent inconsistencies. It will be noted that in the substitution of one piece of apparatus for another, the authors make capacity alone the basis of capitalization charge, improved efficiency being entirely ignored. Depreciation is apparently taken to include only obsolescence and inadequacy, while extraordinary accident and "calamity", such as the floods which lately visited many plants in the central west, items which must be taken care of by reserves rather than insurance, are omitted.

The figures given in Table I, Life Expectancy, are stated to

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be, what the authors believe, "fairly representative." It would be interesting to know upon what basis such statement is made, as the figures are not in accordance with those widely used and authoritative figures given, for example, in the speaker's paper on "Depreciation", presented before this Institute two years ago. It would seem only fair to criticize the use of figures which do not agree with those more or less well established and authoritative, unless the authors offer some explanation as to why their figures differ and reasons for their acceptance. The introduction of such random data, which is too common among writers of papers before this and other societies, results only in confusion and lack of uniformity, for which the profession is justly criticised. By way of further illustration, all buildings will not have the same life expectancy and the authors should differentiate between the character of buildings referred to; for example, wood, brick, steel or monolithic concrete, the lives of which will be quite different. The same with regard to scrap value. On what do the authors base their value of 5 per cent? Certainly it does not relate to wooden buildings, nor to concrete buildings, unless in exceptional cases, and the speaker has found 8 per cent is about the correct figure for the scrap value of brick and steel structures.

A similar line of criticism might be made of many of the other items mentioned in the table, the lives of which are unduly short, or of which the parts may be renewed almost indefinitely. The publication of such figures by men of such standing as the authors, leads to their use in misleading and unfair ways, by inexperienced and prejudiced engineers.

It is a mooted question whether depreciation should be considered as one account, of which wear and tear, obsolescence, accident and inadequacy are all separate classes, or whether maintenance and repairs should be considered separately and depreciation used merely in reference to other class of deterioration. The objection to dividing the item is that it is difficult to say when repairs and renewals are maintenance or depreciation. As a matter of fact, all wear and tear requires renewals, the distinction usually being, that when the renewals are small as to parts or in cost, they are charged to maintenance, and when relatively large or expensive, they are charged to depreciation. Such classification is purely arbitrary and in any system consisting of a large number of parts and the investment of many millions of dollars, all renewals can properly be treated as wear and tear. The cost of such replacements do not affect the income any more than does the wear and tear account affect the income of a company having fewer parts and smaller investment. Many companies are following the procedure (which is simpler and ordered by some Public Service Commissions, and therefore, in the opinion of the speaker, preferable) of establishing in advance, an annual amount, which is set aside for depreciation of all classes, usually appropriating

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this out of revenue month by month. This depreciation account is then charged month by month with the actual expenditures made for maintenance, repairs and renewals, the balance being carried forward as a depreciation fund. This method of accounting avoids the constantly occurring and irritating question as to which account, maintenance or renewals, the particular item being renewed, is properly chargeable. The importance of having a definite and uniform rule for charging maintenance and depreciation is at once apparent to anyone who is attempting to compare classes of expenses in two or more plants. In any case the proposal to periodically check and adjust the annual amount set aside to cover depreciation is to be commended and is being done by some corporations.

It appears to be unjustifiable on the part of the authors of this paper, to use 5 per cent as the basis of return on capital invested, even by way of illustration. The curve, Fig. 1, showing the cost of power, based on a 5 per cent return, is misleading, as no utility company can secure funds on any such basis, and the authors' own company very properly insisted upon and recently obtained a return of practically $8\frac{3}{4}$ per cent (including about one per cent for amortization) on its investment in the New York subway, and the State of Tennessee this week has had to pay 6 per cent to refund its public debt. Why then should such an erroneous figure as 5 per cent be used.

In fact, any return on the investment in mere physical property, as apparently proposed by the authors, is entirely insufficient and unfair, if "total production costs" are being sought; the proper intangibles or overhead capital expenditures should be included in order to obtain total production costs.

Item No. 28 defines load factor in relation to the maximum one-hour load; this is a longer period than would be accepted by many operators, as fifteen minutes, five minutes, or even less is frequently the basis on which load factor is estimated. The statement that the cost of labor varies with the load factor, reaching a minimum at about 25 per cent, would undoubtedly depend to some extent upon the size of the plant and number of units. It would seem that the statement that the cost per kw-hr. output varies approximately as the inverse fourth root of the load factor, should be amplified so as to show actually the conditions under which this rule has been found to apply, size of units, capacity of station, fuel and labor costs, etc., and what variations from these conditions are known it is possible to make without appreciably affecting the rule.

With reference to the paper as a whole, the question may be raised by some as to whether the subject discussed is a proper one for consideration by a scientific engineering organization. The speaker desires to go on record as endorsing the presentation of such an eminently practical engineering paper before the Institute, and further to acknowledge an obligation to the authors for the enunciation of their inverse fourth root rule,

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which it is hoped will be found to apply, at least, approximately for all stations.

**Carl Schwartz**: Messrs. Stott and Gorsuch begin their paper by saying, "the need of some uniform method of accounting for the determination of the cost of power in steam plants has been long felt."

There is no doubt that this need exists because it is not alone difficult to draw a direct comparison between the cost of power from stations operating under different conditions, but in some cases even between two stations in the same locality, using practically the same kind of coal and operating under similar load characteristics.

The speaker is connected with a company which has for several years exchanged power station operating costs with other companies and knows that this exchange has been of benefit. In one case the cost of current for operation and maintenance of a modern power generating station containing four 5000-kw. units has been reduced from 0.67 cent. in 1908 to about 0.45 cent. per kw-hr. in 1912. It is true that the output of this station has increased from about 40,000,000 kw-hr. to about 76,000,000 kw-hr. per annum in the same period, and the average cost of coal has been reduced by about 11 per cent, still an appreciable amount of the reduction in cost of current can be attributed to the knowledge of other station performances. The cost of current at the present time is not as low as in some other stations of larger capacity, still considering the price of coal, and the fact that the turbo-generators have a steam economy of about 18 lbs. per kw-hr., it is believed to be nearly as low as it can consistently be expected. If the steam economy of the turbo generators were 13 lb. per kw-hr. the cost of current would be about 0.37 cent.

The paper covers the elements entering into the cost of power in a comprehensive manner and gives a complete analysis of the conditions to be considered. The following comments are believed to be applicable.

A comparison of the cost of power should be made as simple and short as can consistently be done in order to relieve the operating companies of unnecessary accounting and computations, as otherwise some companies may decide that the expense of keeping their accounts in the manner prescribed and making the computations to bring their operating and maintenance costs on a comparable basis, exceeds the expense they feel justified in incurring. The more companies can be found to contribute to the statistics, the greater will be their value, and it would be unfortunate if all contributions to the cost statistics that are possible to secure could not be obtained.

A high degree of accuracy in making comparisons of station performances is desirable, still some expenses cannot readily be compared and for this reason it may be permissible to sacrifice a certain degree of accuracy for simplicity.

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On pages 1100 to 1102 the items of production costs and production repairs costs are covered in full detail. To make a comparison between two or more stations it would seem that many of the items enumerated could be consolidated. If differences occur an investigation would readily reveal the reason and thus burdening the regular reports with a relatively large number of detail items of minor importance would be avoided.

Item PA, Management and Care, appears as an operating charge only. Some of the items thereunder, however, are chargeable likewise to maintenance and while the proportion chargeable to maintenance is small, still room should be provided for management and care under production repair costs.

The costs of the various items of production and production repairs are shown in cents per kw-hr. output. Some of these figures may not exceed a few hundred dollars per year and expressing them in cents per kw-hr. would take considerable time to compute and require many decimals.

I would ask Mr. Stott whether he sees any objection to the use of the total costs in dollars and cents for the detail items, making the distribution in cents per kw-hr. in the summary only, as given at the top of page 1103. An additional comparison would be afforded by expressing each of the items in percentage of the total.

Injuries to employees and other personal injuries and property damage is covered by group PJ-General, c and d. In investment costs, group *IC*, insurance covers the settlement of claims for personal injuries and property damage. Thus, accidents are charged against the operating account or to capital account, depending on whether the company carries insurance or not.

Fire or accidents will influence the cost of power from a station carrying insurance to the extent of the cost of insurance and from a station not protected by insurance will be correspondingly less except in case of fire or accident when the cost will be suddenly increased.

The accounts of a company carrying insurance and another not carrying insurance would, therefore, not be strictly comparable unless the condition for each station is made clear.

Mr. Stott covers very fully the matter of amortization and divides these charges into; first, physical depreciation, and second, functional depreciation. Physical depreciation is disposed of by charges against maintenance under the assumption that the plant will be maintained at 100 per cent efficiency.

For functional depreciation a comprehensive method is outlined which permits a readjustment from time to time to either make allowance for changes and additions or to correct certain assumptions as to the life of apparatus and machinery, should there be reason for doing so. While the flexibility of the method may be attractive, still it involves considerable labor and as an estimate of the life and the scrap value of the apparatus largely depends on the judgment of the person making the estimate descrepancies are apt to occur which tend to offset the

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advantages the method otherwise offers. Furthermore, the total life of 75 years for buildings may be impaired by radical changes after the shorter life of the machinery expires.

For comparing functional depreciation in place of this method, and for the sake of simplicity it is suggested to consider an average life of 30 years for the entire station and after making a deduction of 5 per cent for scrap value, charging a sufficient amount annually to equal, with interest compounded annually at 4 per cent, the prevailing investment.

By prevailing investment is meant the original cost of the plant complete excluding land but including all expenses chargeable to capital cost, like discount on the sales of securities, interest during construction, tests, preliminary operation engineering and contingencies. To this to be added annually the cost of additions and betterments less the original cost of any apparatus removed.

While it is realized that almost any form of depreciation offers room for objections, still it is believed that if some definite method like the above could be agreed upon and used as a basis for all comparisons of power station costs it would greatly simplify the work.

Referring to the Analysis of Production and Production Repair Costs, item 9, "average daily wages per man"—to compare the costs per kw-hr. net output of two independent plants on the same basis, a reduction factor is to be applied to labor only, the difference to be added to or subtracted from the total cost of production plus production repairs per kw-hr. net output.

This method would adjust differences in the cost of labor of different localities. It seems, however, that it would not allow adjustment in case the average daily wages per man are higher or lower by a different class of labor employed. For instance, one station may burn hard coal and be equipped with hand-fired grates requiring a certain number of men. Another station may be equipped with automatic stokers reducing the number of men in the boiler-room to a minimum though the average wages per stoker operator are higher than per ordinary fireman, thus raising the average cost per man for the entire station.

As to the reduction factor for labor, I have in mind the conditions of two stations, one burning soft coal with automatic stokers and the other hard coal screenings on hand-fired grates. The cost of labor and coal at these stations for the year 1912 compares as follows:

| | Stokers. | Hand-fired-grates. |
|---|---|---|
| Net output, kw-hrs. | 83,000,000 | 47,000,000 |
| Boiler room labor, per kw-hr. | 0.042 cts. | 0.0984 cts. |
| Coal, per kw-hr. | 0.314 cts. | 0.3127 cts. |
| Cost of coal per 2000 lb. | 2.37 | 1.63 |
| Coal per kw-hr. | 2.66 lb. | 3.8 lb. |
| Total operation and maintenance. | 0.492 cts. | 0.593 cts. |

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The cost of labor per kw-hr. in the station equipped with hand-fired grates is over twice as high as in the station equipped with automatic stokers due to the greater number of men necessary for hand-firing.

The average cost per fireman is less than per stoker operator and this condition, if Mr. Stott's method was followed, would lower the average for the entire station force.

I am not sure whether a method can readily be found to make an adjustment in satisfactory form and the reason for calling attention to these possible inaccuracies is not to suggest further refinement but rather to suggest simplification in the method of comparing the cost of power, even if some accuracy has to be sacrificed.

The curves in Fig. 1 of the paper clearly show the influence of the load factor upon the cost of power and those referring to the cost of production and production repairs appear to be sufficiently close to be used for bringing these costs on a comparable basis. While I believe that in this case, as in others, simplicity should be the keynote, still it will be difficult to find a simpler method that will give satisfactory results. After sufficient data have been collected it should readily be possible to adjust the curves and equations if necessary and, therefore, the method given by Messrs. Stott and Gorsuch should form a good basis for making adjustments for load factor.

Daily factor of load is expressed as:

$$\frac{\text{Actual net output for day of 24 hours}}{\text{Net maximum hour's load} \times 24} \times 100$$

and it is stated that load factor based upon the rated capacity shows a wide amount of variation, and for this reason it is proposed to base the load factor upon the actual maximum one hour load.

To deliver the maximum load a certain number of machines is required and their capacity may or may not agree closely with the load to be carried.

The load factor could readily be expressed by:

$$\frac{\text{Net output in kw-hr.} \times 100}{\text{Generator capacity running} \times \text{machine hours.}}$$

It is believed that this method will give more comparable results because the investment and the costs of operation and maintenance have less relation to the maximum hours load than to the capacity of the machines and their time of operation.

To adjust for the relative value of coal a method is proposed which corrects for the difference in B.t.u. the cost of coal and the percentage of ash.

There are other factors entering into the value of coal, namely, volatile matter, which may curtail the capacity of the furnaces by producing excessive smoke, sulphur, lime, iron and silica which may increase the operating labor and furnace maintenance, and the percentage of ash and amount of clinkers enter into the cost of ash removal.

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Not all of the above items may be of sufficient moment to require adjustment, but some of them it would seem should be taken into consideration in comparing performances, because some plants may give better results than others though the figure of merit for coal, if computed on the basis suggested, is the same.

Section III covers General and Miscellaneous Administration expenses which is proposed to be charged to the cost of power in the proportion the total operating and maintenance cost of the power plant bears to the total running expense of the corporation.

With some companies a steam power plant is a relatively small item of its business and the distribution of the general and miscellaneous administration expenses as outlines will be difficult. It would be better to omit all of these items, because they do not affect the comparison of the cost of power sufficiently.

The scope of the program of comparing the costs of power could readily be extended to cover not alone the cost of power at the busbars of the power stations but up to the third rail shoes or overhead collectors of electric locomotives or the customer's meters of electric lighting companies.

The summary of a form for operating and maintenance costs from power stations to the third rail which has given satisfactory results is shown below:

| Items. | Total cost | Cost per kw-hr. |
|---|---|---|
| *Power Stations:* | | |
| Net a-c. output, —— kw-hr. | .... | .... |
| Operating labor, | | |
| Operating material, | | |
| Maintenance labor, | | |
| Maintenance material, | | |
| Total at power stations, | | |
| (1) *Total at Train Shoes,* | .... | |
| *Substations:* | | |
| Net d-c. output, —— kw-hr. | .... | .... |
| Operating labor, | | |
| Operating material, | | |
| Maintenance labor, | | |
| Maintenance material, | | |
| Total at substations, | | |
| (2) *Total at Train Shoes,* | .... | |
| *Cable Department:* | | |
| Alternating current: | | |
| Total a-c. input to subs., etc., —— kw-hr. | .... | .... |
| Maintenance labor, | | |
| Maintenance material, | | |
| Total a-c. cables, | | |
| (3) *Total at Train Shoes,* | .... | |
| Direct current: | | |
| Total d-c. output at third rail, —— kw-hr. | .... | .... |
| Maintenance labor, | | |
| Maintenance material, | | |
| *Total at Train Shoes,* | | |
| *Third Rail:* | | |
| Total d-c. output at third rail, —— kw-hr. | .... | .... |
| Maintenance labor, | | |
| Maintenance material, | | |
| *Total at Train Shoes,* | | |
| *Grand Total at Train Shoes,* | | |

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(1) This figure to be obtained by multiplying the cost per kw-hr. at power station by 100, dividing by efficiency in per cent from power station busbars to train shoes.

(2) This figure to be obtained by multiplying the cost per kw-hr. at substation d-c. bus bars by 100, dividing by efficiency in per cent from d-c. substation bus to train shoes.

(3) This figure to be obtained by multiplying the cost per kw-hr. at substation a-c. bus bars by 100, dividing by efficiency in per cent from a-c. substation bus to train shoes.

The fixed charges for transmission lines, substations and third rail could be handled in a similar manner as for power plants.

The above can be briefly summarized as follows:

1. Condense the comparison and simplify the accounting and computations as far as possible.

2. Space should be allowed under the maintenance account for certain expenses under management and care chargeable thereto.

3. For all detail items total cost figures could be used instead of cents per kw-hr., to save labor and avoid small decimal fractions. The cost of items in the summary if expressed in per cent of total would permit additional comparison.

4. Simplify the method of calculating functional depreciation.

5. The average daily wages per man are not only determined by the cost of labor in different localities but also by the nature of the equipment and the class of labor employed.

6. To express load factor the following expression is proposed:

$$\frac{\text{Net output in kw-hr.} \times 100}{\text{Generator capacity running} \times \text{machine hours.}}$$

7. The figure of merit and reduction factor for determining the relative value of coal is believed to require additional adjustment. If a certain quality and cost of coal could be agreed upon as standard, comparison should be facilitated.

8. It is suggested to omit Section III, general and miscellaneous expenses.

9. The scope of the comparison of the cost of power could be extended to cover the cost of current up to the point of consumption.

In closing, the speaker wishes to express his belief that the authors' paper covers the subject so fully that with relatively minor revisions it should form an excellent basis for the Standards Committee as a standard method of comparing the cost of power.

**William McClellan:** It seems to me that this paper must be taken, as the authors have suggested, by a committee of the Institute and gone over line by line. More simplicity appeals to me; certain mechanical features about the report,

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such as a better choice of letters, corresponding to classes, I think, can be somewhat improved.

Inasmuch as I have had some experience with public service commissions from the commission side, I must say in answer to the fear that the companies will object to doing the various things which are suggested in this paper, that there are two answers.

First, the companies themselves are finding out that there is nothing to object to. A number of companies in New York City are comparing costs with each other, and the result of this comparison is more or less public, but not entirely so. In the second place, companies will have to do it sooner or later.

The desirability of this sort of thing is, first, that we want it for ourselves—the companies themselves need it. A man who does not know just what he is doing in the way of costs in the production of power is not running his business properly. In the second place, the man who is not able to compare what he is doing with what the other man is doing, cannot make proper progress. First, it is necessary to know what we are doing for the sake of having the knowledge, and secondly, to compare our operations with those of others, which is important in all departments of life. Otherwise we cannot tell whether we are moving or not, and especially whether we are moving in the right direction.

I like the general plan of the paper very much. I think the Institute has had a tremendous lot of work done for it of the very highest quality. Just where certain items should be placed, I think there is a little doubt. When I first read the paper, I wished for educational purposes that depreciation could be put among production costs. Many men fail to realize that depreciation or amortisation, if you please, is an expense. There are many men who say: "Why should we take part of our profits and put them into depreciation?" The reply is that you are not earning profits until you have paid for every item you require in the operation of a plant. When the machine is operated, it is burning up just as surely and certainly as the coal under the boiler. You do not see it going on in just the same way, but it is as surely taking place.

One of the speakers spoke of calamities. If a building is destroyed by fire, I do not know how far you will be able to go into a depreciation fund for that. I think from the viewpoint of modern methods you would be unfortunate if you did not have insurance on the building.

Take the division of depreciation into large and small repairs. It is an operating expense. There is a question if you reduce these things into a formula, as to what effect it will have. You may pay for the repairs directly out of this year's operating expenses, or you may defer them and pay them five years from now in the form of larger repairs. That is a matter of bookkeeping, but when you introduce depreciation into a formula

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and have the results comparable with the results of other companies, it does make a difference, and that would require a great deal of thought.

Companies must be put in different classes, or you will not be able to compare them justly. It would not do to compare a small station with a large one, or one station with another station of a totally different type. Therefore we must put the stations, or whatever we are comparing, into various classes, so that they can easily be taken care of.

Finally, I want to make a motion, Mr. Chairman, if I may. It has been suggested by the authors, and in following out their wishes I desire to move that it be the sense of this meeting that the suggestions made in this paper be referred to the Board of Directors of the Institute, that they may refer it to a proper committee for immediate action, the meeting believing that it is extremely important that the subject be brought as soon as possible to a practical basis for use by the Institute members.

**C. O. Mailloux**: I take pleasure in seconding the motion. I consider that the Institute is to be congratulated again in having a paper of this kind from Mr. Stott. It is especially to be congratulated upon the fact that all of Mr. Stott's papers on central station economics have been read before the Institute. You do not appreciate that now so much as you will a few years from now, when you look back and see the evolution of central station economics and come to realize that Mr. Stott is the man who really put the matter on a sound basis. Some of his papers will then be recognized as classics and we will appreciate their value. A few years hence engineers will look upon Mr. Stott's papers with the same high respect that is shown the classic writings of Rankine.

I think it is very important, as Dr. McClellan said, that this paper should be put in the hands of an intelligent committee especially fitted and qualified to deal with the many questions which the paper brings up, so that the valuable data and information contained in this paper may be put in such form that it will be made available to the Institute members and to the profession of engineering in general.

**Peter Junkersfeld**: I feel that too much has, perhaps, been attempted. However, as Mr. Stott has said, the matter is presented as a target, and with that explanation, it is very well put, indeed. If this paper is referred to a committee in accordance with the motion pending, I would suggest that such committee look over the field carefully and see what has already been done in this connection.

We must not assume that no standardization so far has taken place. I would call attention to the fact that both the National Electric Light Association and American Electric Railway Association have a standard classification of accounts, and as far as power house general classifications go they are practically the same. The National Electric Light Association has nine

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general headings for the power house expense and the American Electric Railway Association eight. I have here a memorandum showing the number of sub-divisions under the various headings of power plant expenses as divided by the Commonwealth Edison Company, which follow closely the National Electric Light Association; those proposed by Messrs. Stott and Gorsuch; and those proposed by the American Electric Railway Accountants Association. (See table on next page.)

The most important thing is to consider the general headings, say eight or nine, so that when we compare these in different plants we will know what we are talking about. If we find a discrepancy, then we can analyze and subdivide, but the subdivisions must, in many cases, be different, because there are many local conditions that will affect one place as compared with another, but the general headings ought to be alike.

There are many details which might be discussed. One very important point made was that the net output should always be considered and not the gross output. It is surprising how many people throughout the country make that error. It is obvious that it is not worth any further discussion. Net output, in my judgment, should always be used, and there is no excuse for using gross output.

So far, I am speaking entirely of operating cost. Now, on the investment side of the business, standardization is going to be more difficult, and, I would suggest, as a matter of practicability, and of making the most headway, that your committee concentrate its efforts, first, on comparison of operating costs.

I am afraid if they attempt to standardize the entire thing at one time, they will meet with opposition in different parts of the country. There are many conditions all over the country where, if a company should show all its investment costs, it might be subject to difficulties from people who, through ignorance, or through intent, might misuse this information.

It is possible, also, to segregate general expense a little too far in that connection. You cannot in any line of business, whether it is a central station lighting company or a traction company, assume that the power house is an absolutely independent business by itself. Therefore you must have some general expenses which cannot be apportioned correctly. You can approximate them, but to say as a matter of record, that month by month so much should go against that station, and so much against another, is not always getting at it in accordance with the actual condition. There may be some extraordinary work, or some contingency, that will involve one power house a certain length of time. During this time any general expense you ordinarily apportion to that power house would be far too low, and when that state of affairs occurs you are fooling yourself. General expenses do not have a constant ratio to each of different elements of the business.

Load factor is very important, and I am glad the authors

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CLASSIFICATION OF POWER PLANT EXPENSES.

| Commonwealth Edison Company | Proposed by Messrs. Stott and Gorsuch | American Electric Railway Accountants' Association |
|---|---|---|
| | Management and care:<br>10 Subdivisions. | |
| (1) Labor for operation:<br>6 subdivisions. | Boiler Room Labor:<br>12 subdivisions.<br>Engine room labor:<br>7 subdivisions.<br>Electrical labor:<br>9 subdivisions. | Powerhouse operating labor:<br>No subdivisions. |
| (2) Fuel:<br>5 subdivisions. | Fuel:<br>7 subdivisions. | Fuel:<br>No subdivision. |
| (3) Water:<br>No subdivision. | Water:<br>6 subdivisions. | Water:<br>No subdivisions. |
| (4) Lubricants:<br>No subdivision. | Lubricants:<br>2 subdivisions. | Lubricants:<br>No subdivisions. |
| (5) Station Supplies and expenses:<br>7 subdivisions. | Production supplies:<br>7 subdivisions.<br>Station expenses:<br>4 subdivisions. | Power plant supplies:<br>No subdivision. |
| — | Operating general expense:<br>5 subdivisions. | — |
| (6) Maintenance and repairs of station building and property outside of station building:<br>4 subdivisions: | Building repairs:<br>6 subdivisions. | Building repairs:<br>No subdivision. |
| | Repairs to furnace and boilers:<br>10 subdivisions.<br>Repairs to boiler accessories:<br>8 subdivisions. | |
| (7) Steam equipment repairs:<br>8 subdivisions. | Engine repairs:<br>5 subdivisions.<br>Repairs to engine accessories:<br>5 subdivisions.<br>Repairs to piping:<br>10 subdivisions:<br>Repairs to tools:<br>4 subdivisions. | Equipment repairs:<br>No subdivision. |
| (8) Repairs to electrical:<br>4 subdivisions. | Repairs to electrical generators:<br>5 subdivisions.<br>Repairs to electrical accessories:<br>8 subdivisions. | — |
| | Repairs general expense:<br>4 subdivisions. | |
| (9) Purchased power:<br>No subdivision. | | Purchased power:<br>No subdivision. |

SUMMARY.

| | General Headings. | |
|---|---|---|
| Nine. | twenty. | Eight. |
| | Subdivisions. | |
| Thirty-four | One hundred and thirty-four | None. |

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brought it up. They have pointed out that there is a good deal of misunderstanding all over the country as to load factor. Every time load factor is used it should be stated whether it is daily, monthly or annual load factor, and what kind of peak it is based on. In dealing with load factors and maximum demand, we should be very definite and know just what we are using, know that it is not guess work, something really substantial, an actual observation of all the elements that make up load factor.

In figuring investment costs, spare capacity is a big item. You may be able to operate under certain conditions with 10 per cent spare capacity. Under other conditions, with a growing business, that may be much too close. I know of situations where 20 per cent is too close, because of the rapid growth of the business. That does not mean the company always carries 20 per cent, but that is the figure when everything goes well. If there are labor troubles or manufacturing difficulties, that 20 per cent in one year may go down to 5 per cent. Such possibilities must be provided for.

As to maintenance and depreciation, these items often do not tell the whole story. If a man has a very low maintenance account it is well to look back of that account and see what his machinery looks like. We must consider very definitely both maintenance and depreciation when we speak of these terms. When we look over the past, it is one matter to assign a certain amount for depreciation, but when we look ahead we do not know what it is going to be, and we must allow a reasonable amount to cover what it may be. Past and future depreciation are two separate things and should never be confused.

**D. B. Rushmore:** The cost of power is the basis of nearly all engineering work. Practically everyone is manufacturing something in which a cost comparison is the basis for decision between different paths of action.

The specific point under discussion this morning is one phase of a very general subject that includes the cost of articles manufactured in practically every walk of life. The farmer is manufacturing his products, the railroadman manufacturing transportation, the electrical engineer manufacturing electricity, or whatever else it may be, and the very fundamental part of this engineering work is the cost of the product. This cost is generally recognized as being divisible into a quantity which varies according to the output, and when the consideration of this specific case comes up during the coming year it will be of interest to those working on it to consider the broader underlying fields which are necessarily involved.

The usefulness of this paper at the present time is not only to operating men, but also to a field in which the speaker happens to be engaged, that of manufacturing companies. At the present time the difference between hoisting by compressed air or hoisting by electricity is very largely one of the cost of the output,

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and the basis of comparison is not very easy. It is very difficult to get the advocates of different systems to agree regarding the items which should enter into the comparison, and until such a decision is reached it is very hard to play the game in a proper way.

In connection with the amortisation, there is a different class of amortisation in the general field involved in those pieces of machinery and in those products which have a natural life. An incandescent lamp has a limitation to its usefulness which is more or less fixed, a motor approaches the dividing line. We expect to wear it out and throw it away. Larger machinery does not wear out, but individual parts do, and a few parts can be replaced and the condition of the machine kept up to its original shape.

The fact that up to the present time it has been very difficult to determine the actual costs of power for different plants and operating conditions, represents a condition fully justified by the fact that for a concern, individual or company, to give out its manufacturing cost, it must be in a position where these cannot be used to affect its condition adversely, and the advent of the Public Service Commission, with the protection that it gives, along with its other features, is one of the reasons why it is now permissible to give more publicity to these figures. A suggestion is made for the coming year that in order to get the most benefit from the tree which is going to grow from this seed planted by Mr. Stott and his associate, that an effort be made to bring the engineers of the Public Service Commission into the Institute and to have them in some way affiliated with that part of the organization which will be active in formulating these principles.

**L. P. Crecelius:** The abstract of this paper begins with a statement that power cost should be upon a basis of per kilowatt-hour net output. This looks like a good beginning, and the same principle as laid down here should be applied to every one of the various groups which follow.

In the case of I, Production and Production Repairs Costs: The proposed method seems proper, but care should be exercised before adopting it as standard in its present form to avoid upsetting such existing classifications of accounts as are now standard, in extensive use and under which a multitude of reports are made to various local, state and national utilities commissions. Such little differences as appear in the treatment of the various accounts under this heading as presented in the paper are relatively unimportant and no great difficulty should be experienced in getting them in a proper shape.

In the case of II, Investment Costs: Exception is taken to the proposal of apportioning franchise and revenue tax and charging some of this expense out as cost of power. The reason for this will be given later. The miscellaneous item of this group is open to the same criticism, as will be pointed out later.

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In the case of III, General and Miscellaneous Administration Expenses:

Under this group are a few items which may properly be charged out as cost of power, in the case of certain corporations, but on the other hand, it is proposed in this paper to charge as cost of power, a great many other items which in my belief cannot and should not be included.

The time is indeed opportune for the presentation of this committee report to the American Institute of Electrical Engineers with the request that it go before the Standards Committee, in fact it is past opportune, and I welcome the opportunity thus afforded to present my views on this important matter. There is no question before the power engineer which approximates in importance the question, "what is the *true* cost of power"? He finds himself continually confronted with this question, especially, when the proposition comes before him to decide whether it is wise to continue to manufacture power or whether it would not be better to purchase power from someone who has the peculiar gift of making it cheaper. Again and again, in working up this case little or no information is at hand and rarely can anything better be found to substitute imaginary estimates in order to secure the significance of the value of a great many obvious but ordinarily obscure items such as, for instance, administration expense, casualties, extraordinary maintenance, etc. The greatest use to which this method of determining and comparing costs in steam plants will be applied is in connection with extensions and betterments to existing power plants, and in the matter of determining a proper basis for the purchase of power. Therefore, let the method and its arrangements be such that the true cost of power will result.

My objection to the proposal of permitting much of the general and miscellaneous administration expense of a corporation other than a purely power producing concern to be charged out as power cost is based simply upon this illustration; a railway company operating power plants, is in need of betterments for extensions or otherwise, and is at once approached with the subject of purchasing power. An analysis of its present cost is made and compared with other plants for such information as is available and the possibilities of the betterments as reflected upon the future power cost are brought out. Now, however, if the cost of power is found upon the basis proposed in this paper, it is burdened with a great many foreign miscellaneous expenses such as the salaries of executive officers and the presidents' or directors' travelling expenses to a convention, a portion of which is here proposed to be called power cost; the chief counsel's expenses in connection with appearing before a utilities commission on some question other than power, is also called power cost, and so on. When all these items are added to the cost of power under this plan, it is decided to purchase power rather than to make additional

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investments, and the old equipment is scrapped and written off the books. The result: it is soon discovered that the administration, general and miscellaneous expenses still continue with the corporation which now purchases its power; no reduction in these items is noticed; an allowance for this expense has been made in the cost of the purchased power and we now find the situation where for a great many years the railway is obliged to pay this expense doubled.

The ready means which were at first available to relieve itself of a portion of the expense of these items on the score of power cost as had been practised before shutting down its power power plants, are now gone; secondly, the railway has permitted this previous expense which was called power cost, to be added to all the power which it now purchases. In the face of this situation, my suggestion is, first, that a good rule to follow with reference to these miscellaneous revenue and income tax expense, administrative office and miscellaneous expense, is to charge only that portion which would disappear in the event that power was purchased, and secondly, that the report as presented by this committee should receive more consideration in this respect, again going before a committee and every angle of this complex subject carefully analysed.

**W. G. Carlton:** The summary of operation and maintenance costs or as called by the authors, the "Production and Production Repair Costs", is sufficient for moderate size power stations without going into all of the detail given on pages 1100 *et seq.* A monthly comparison on substantially the same basis as this summary has been made for several years by six electric power stations in and near New York City; these power stations having monthly outputs ranging from 2,000,000 to 18,000,000 kw-hr. This method was shown by Mr. B. F. Wood in a paper on *Electrical Operation of the West Jersey and Seashore Railroad*, presented at the annual convention of the Institute at Chicago in 1911.

In addition to giving the unit costs per kw-hr., it is frequently convenient to have the total cost stated, especially in the smaller items, since a better idea of their importance can be grasped from the total money involved than from the unit costs.

**August H. Kruesi:** This paper will be the more rapidly adopted and be more valuable the more general it is made. I recommend that its scope be extended to include those electric light and railway companies which also produce steam for heating, of which there are a large number in this country. The method would then be applicable to a very large number of industrial power plants which not only produce electrical power, but exhaust steam for heating, and live steam for manufacturing.

I believe in connection with the comparison of costs that the load factor is not sufficient; that we ought to take into consideration not only the machine load factor, but what we may call the station capacity factor. We might divide both the max-

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imum load and the monthly output by two and still get the same load factor, but a large part of the operating cost per unit of output would be twice as great, the fixed charges per unit of output twice as great, and the costs tremendously affected.

The proposed inverse fourth root relationship is represented by curves as shown in the paper, or as in Fig. 2 herewith. I suggest that instead of dealing with the costs per unit of output we should deal with the total output and the total cost. The relationship is then represented by an approximately straight line as in Fig. 1 herewith. This I think will facilitate comparison

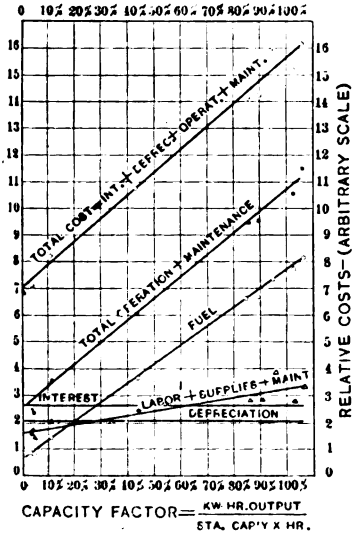


FIG. 1—RELATIVE COSTS FOR 4000-KW. POWER STATION

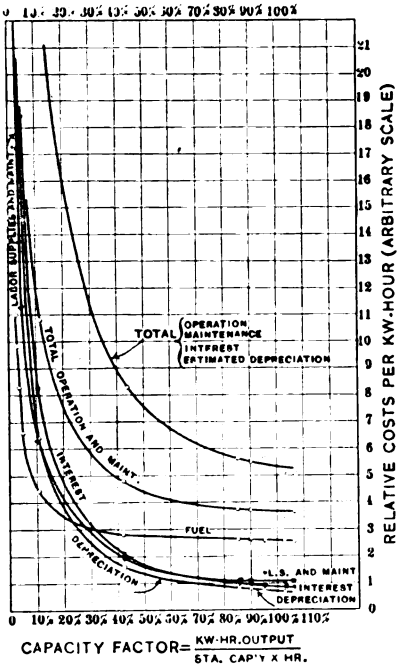


FIG. 2—RELATIVE COSTS FOR 4000-KW. POWER STATION

and will be more readily understood by the accountants and the executives who have to deal with such questions, as well as by the engineers. If it is desired to deal with an equation rather than by plotting, Fig. 1 permits an equation which is much easier to use. The actual performance of a certain steam turbine station is represented by Figs. 1 and 2. Whether the plotted results will always lie on a perfectly straight line or not does not matter and does not make the method suggested any less accurate than the proposed inverse fourth root method.

**D. C. Jackson**: This communication of Messrs. Stott and Gorsuch is an important addition to the extended series of

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truly classical papers which have been produced by Mr. Stott and his assistants. There are two quite distinct and yet closely related features in this paper. One is the proposal that suitable records shall be kept by power companies, and the presentation of a method of keeping them. The other is the statement of Mr. Stott's new inverse fourth root rule of the cost of power as it is affected by load factor. In respect to the latter, I have made some tests of the application of the rule to certain relatively small generating stations which have enjoyed a steadily improving load factor for a number of years and in which the supervision has been good. Comparing the cost of power production plus repairs in the different years, the results come out in satisfactory accord with the inverse fourth root rule, which indicates that we here have a rule which is not only applicable to enormous plants but that it is of general applicability. The rule may therefore be made of much value in studying the advantage to an electric power enterprise which may arise from obtaining a load of improved load factor. It cannot be applied, however, as between two different plants unless they are alike in character and organization. Take one plant with 30 per cent load factor annually, and another plant with 45 per cent load factor annually, and if they are quite different plants, you cannot compare them by this rule without making a prorate with respect to the cost of labor and the cost of coal. Even then one can scarcely expect to get an important comparison between two such plants through the inverse fourth root method. Some other curves will apparently have to be made besides those which Mr. Stott has suggested in the paper, to obtain value from such a comparison, yet it is worth trying to extend the method so that it may be used to find a relative figure of merit for plants under diverse conditions.

I want to speak of the need of extending this study of cost of power beyond the power house. The power house cost is not the whole cost of power to the average company. The average company is not only a manufacturer, but a distributor, and the delivery cost is really one of the most important items in a large number of cases. In fact the delivery costs may be greater than the production costs, and under these circumstances we should not be satisfied to stop at a study of power house costs. This is a problem that needs the joint consideration of the engineers and the auditors, and until such coöperation is brought about in our electric companies, power costs will not be fully figured and known and the lowest profitable prices which can be made for classes of customers will not be determined.

I will not attempt here to go into the details of this paper. A classical paper does not ordinarily lend itself to discussion in detail; and this paper like its type is a stimulus to study rather than discussion.

**Ralph D. Mershon:** Professor Jackson says this study of cost of power should be extended to the distribution system. Let us get

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the terms correct before we extend them any further. I wish we could get a good definition of "load factor". I do not know what a man is talking about when he speaks of load factor. The Institute has a definition for load factor which in itself is far from being definite, and, as far as I know, none of the other electrical societies would conform to the same definition. That is one of the first things to be decided on in this matter, to be agreed upon. Some writers associate the load factor with the station. To my mind the load factor is a characteristic of the load, and it has nothing to do with the station. However, there are some pretty vigorous arguments made on the other side.

**P. W. Sothman:** I agree thoroughly with Mr. McClellan in that we should publish statistics freely. The advantage gained from statistics is very obvious, in that they will help us to make comparisons and stimulate us in our endeavors to obtain the highest efficiency.

I think Messrs. Junkersfeld and Mershon are right with regard to the load factor. The more I think of it, the less I find I know about it. The matter should be referred to the Committee on Standards of the Institute for elucidation.

**H. M. Hobart:** I think a brief allusion should be made to the influence of power factor on the cost of manufacturing electricity. It is apt not to be recognized how greatly the power factor affects the cost. It is generally thought that it affects exclusively the cost of the transmission line, the substations and the distribution system. But when you go into the matter seriously you will find it makes a decided difference in the cost of the electricity as delivered at the outgoing cables of the central station. I am of opinion that in these schedules some account should be taken of the power factor. Of course, also, the ***kind*** of electricity, the ***form*** in which it is delivered to the outgoing cables, makes a large difference. When it is delivered in the single-phase form it costs more than when it is delivered in the three-phase form. The turbines may be of the same size, but when you take into account the increased size of the generators and their lower efficiency when designed for single-phase, it is found to make a very decided difference. The difference is apt to be confused with the circumstance that this single-phase electricity for the purpose for which it is now required on a large scale is always associated with a low power factor. The aggregate result of being required to deliver the electricity at a low power factor, and at the same time in the single-phase form, is to occasion a very serious difference in the cost of electricity, which certainly must be taken into account. It is utterly erroneous to consider that the two kinds of electricity can be produced at substantially the same cost.

I was glad to notice in the paper and also in the discussion the increased tendency to express the capacity of the station, in terms of the millions of kilowatt-hours per annum to be delivered, rather than in terms of the rated capacity in kilowatts,

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because when you come to the rated capacity in kilowatts it is difficult to apply a definite rating to a station. In looking into the matter of the thermal regulation of turbo-generators, one finds that a large generator which will deliver an output of unity for a given ultimate temperature of its windings on the coldest day of winter, will have its capacity brought down to something like five-tenths on the hottest summer day, so that you can hardly put on the nameplate of the generator a rating in kilowatts, when it varies from two to one from the coldest day in winter to the hottest day in summer, provided you want to consider that the limitation to the output of the generator is the temperature of the hottest part of its windings.

**P. M. Lincoln:** I want to make a few remarks on the matter of load factor. We have been told that when we talk about load factor we do not convey any idea of what we are talking about. I do not think that is exactly true. I might use, as an illustration, that if I should say I saw a dog on the lawn, you would know in general what I was talking about, but you would not know whether I was talking of a dachshund or cocker spaniel, or some other kind of dog. If I wanted to convey the idea of what particular kind of dog I was speaking about, I should have to say I saw a male cocker spaniel pup a few weeks old, having such and such characteristics. We are doing exactly the same thing, when we speak about load factor. When I say load factor, you know in a general way what I am talking about. It is a generic term, not specific; it is the difficulty with the speaker, as a rule, that he does not define exactly what he means. But if I should speak of the daily load factor, based on a fifteen minute maximum, you would know what I meant, and if I should speak of a yearly load factor, based on a one hour maximum, you would know what I was talking about. The term "load factor" is perfectly defined in its generic sense, and if the speaker wishes to be more definite, it is up to him to put in the proper qualifications.

**Ralph D. Mershon:** Will your remarks apply to the case where the load factor is the ratio between the average load on the station and the generating capacity you have in it?

**Paul M. Lincoln:** That is not load factor, that is something else.

**Ralph D. Mershon:** Most people call it load factor.

**Paul M. Lincoln:** Load factor is something that applies to the load and not to the station that carries the load.

**W. S. Gorsuch:** The formula on page 1130 has been criticised by Mr. Floy, because "general and miscellaneous administration expenses" are not included. These items can be added in the same way as "Investment Costs," making correction for load factor only, as explained on page 1128. However, it is not the purpose of the formula to express the total cost of power but to show after applying correction factors the relation of those costs, which depend upon the station design,

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efficiency and management, as illustrated and explained on pages 1126 and 1127.

To compare two plants from a purely operating point of view, it is proposed to correct for the "Average Daily Wages per Man" and the cost and quality of coal or "Figure of Merit", as these two items are materially affected by local conditions over which the station manager may have little or no control. The other items of production and production repairs are practically factors of station condition, design and management and can be directly compared without making any corrections. The Investment and Administration Costs are independent of how a station is operated or managed, and these items can be compared directly on kw-hr. net-output basis without any corrections, to see whether or not either station is unduly burdened with such charges. One plant may be carrying more surplus capacity than is necessary and for which there may not be any demand in the immediate future. If a correction factor were applied to every item of cost, a hypothetical station would be set up equivalent to the plant taken as standard of comparison, with the natural result that the power costs for both plants would be practically the same.

I do not know of any life expectancy table that is generally accepted by engineers, as has been stated. Further, the life expectancy table used in the illustration is not given for the purpose of setting up a standard, for there cannot be any standard in the sense that the table is used in the paper. An independent life expectancy table should be established at the beginning for each plant and readjusted at certain periods. If two plants are equipped with similar apparatus and installed about the same time, the life expectancy tables at the start would naturally be the same. If, on the other hand two plants should be installed a period of years apart with similar equipment the life expectancy tables may be correspondingly different for certain apparatus. One company may purchase and install apparatus that will soon become obsolete while another company may have had similar apparatus in service for several years, in which case it would not be consistent to apply the same life expectancy table when each plant was put in operation.

In comparing the power costs of any two stations with a view to purchasing and interchanging power or combining plants, it is essential to see that the life expectancy tables are not relatively too low or too high. What the whole scheme really amounts to is to establish a reasonable independent life expectancy table at the beginning for each plant, so that the percentage estimated to be set aside will be sufficient to replace the apparatus when it becomes obsolete or inefficient.

The expenses of personal injuries, other property damages and pensions, chargeable to the power plant should be determined independently, as they are relatively small in comparison with those of other departments of a railway or lighting company.

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These expenses may be incurred by straight operation or during repairs and it is proposed to charge them to production or production repairs as the case may be.

Mr. Schwartz seems somewhat apprehensive regarding the application of the "Reduction Factor" for labor when comparing a hand-fired with a stoker-operated plant. While it is true that there will be more men, and that the "Average Daily Wages per Man" may be lower in a boiler room that is hand fired than in one using mechanical stokers, yet it is equally true that one plant may have too many other classes of men in the station due to bad management, poor arrangement and kind of equipment etc. If it is desired to know what the stoker operated plant with its entire equipment can do, provided the lower price of coal and lower (possibly) "Average Daily Wages per Man" of the hand fired plant can be obtained, it will be perfectly fair to apply the "Reduction Factors" for coal and labor as outlined in the paper. It may be that a hand-fired plant has a lower "Average Daily Wages per Man" with practically the same "Figure of Merit" of coal as the stoker-operated plant with which it is being compared, in which case it will be necessary to increase the cost of labor of the hand operated plant for comparative purposes.

In reply to Mr. Schwartz's suggestion that in determining the "Figure of Merit" of coal, volatile matter, sulphur and other ingredients than that of ash should be considered. I wish to say that it would be very difficult to correct for many of the factors, and further, the variation of some is so small as not to materially affect the "Figure of Merit". For illustration, in comparing two coals it will require a difference of 30 per cent in hydrogen to make a difference of about 1 per cent in the "Figure of Merit".

Regarding the question whether it would not be better to give the total cost of each item under the various groups instead of the cost in cents per kw-hr. net output which in some cases will be a decimal of several ciphers, it will not be possible to compare corresponding items of two stations on the same basis unless reference is made to the kw-hr. net output.

The charges covered by Group P.A. "Management and Care" would naturally be distributed among all the other groups, but this would be very difficult to do, as some rule or assumption of distribution would have to be made which would vary for different stations. For comparative purposes it seems to be advisable to group these costs as outlined.

If the percentage to be annually charged to the "Amortization Fund" is determined by using the average weighted life and the total cost of the plant, it will be found after a period of years that there will not be sufficient funds to cover the required replacements. The proper way to arrive at this percentage is to determine the amount to be set aside annually for each main item as outlined in Table I and then determine the rate by taking the total annual charge and the total amount to be amortized.

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Regarding the question as to whether the relationship between load factor and cost of production plus production repairs as expressed by the inverse fourth root law is applicable to small plants, this law will hold for plants of 5000 kw. capacity and probably smaller.

There seems to be a difference of opinion as to whether the "General and Miscellaneous Administration Expenses" should be included in the cost of power. For the purpose of comparing the cost of power from an operating point of view, it is not necessary. However for the purpose of exchanging or selling power a portion of these expenses should be included in order to obtain the true cost of power to the company. A portion of the Administration expenses is required to make and keep the plant a going concern, such as the purchase and distribution of fuel and material, drawing up contracts for materials and apparatus used in repairs, adjusting claims, relief, handling pay rolls, etc. Taxes are also imposed on the company for the privilege of operating.

Aside from the above, if a company desires to determine whether it will be cheaper to purchase power, it will be necessary to exclude such items that will not disappear and include those that will disappear in the event of power being purchased. This not only applies to "General and Miscellaneous Administration Expenses" but also to "Investment Costs". For instance, the bondholders may require that the plant be kept intact and not dismantled and scrapped. In contemplating the purchase of power, the conditions should be considered under which the proposition is made before comparing power costs, as items that will disappear in one case may not disappear in another.

I do not see that it is necessary for any classification of accounts that may be decided upon for determining and comparing power costs, to conform strictly to any Public Service Commission Classification. However, the grouping should be arranged so that any Public Service Report can be compiled from it.

The amount of the miscellaneous items in each group will be relatively small as any appreciable expenditure can be charged to a definite item.

**E. D. Dreyfus** (by letter): We have long felt the need of establishing criteria for measuring the performance of our power plants. If the movement Mr. Stott and his associate have inaugurated will be conducted in the manner it deserves, benefits to industries are bound to result. Some stations under efficient and progressive management have established results which should be fairly taken as bench marks from which other stations should measure their performance.

Conditions, of course, vary widely and the authors have focused attention upon those which were of the most serious nature and have proposed formulas to reduce the operating conditions of different plants to a more or less common basis.

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In connection with the formula at the bottom of page 1128, it is the writer's opinion that in a great many plants there would be either difficulty or a great deal of additional work to adequately and satisfactorily determine the percentage of combustible in the ash. For simplification I would propose that this formula be modified so that the "figure of merit" could be ascertained directly from the coal analysis and the total effect of the percentage of the ash taken care of somewhat in accordance with the results obtained by Mr. W. L. Abbott in a long series of tests conducted in Chicago upon the effect of variation of percentage of ash in the fuel and which was published in the proceedings of the Western Society of Engineers, 1906. Also, I wish to call attention to the fact that the use of the long ton confines this formula, more or less, to sections in and around New York. I believe according to government reports that over ninety per cent of the coal mined is sold on the short ton basis.

The authors have adopted a factor termed, "The Average Daily Wages per Man". In this connection I might mention another point which might have some bearing, and that is that some operating companies work on a very much closer margin as regards the number of men engaged in running the power house than others. Some companies hold more men in reserve for emergency and figure that the cost of this insurance is worth while; while, on the other hand, other companies view the matter from the standpoint that it is best to keep the labor cost down to the minimum and economy thus affected will more than offset any probable loss due to emergency which might have been largely offset by having extra men working around the power house and in readiness to do emergency duty.

As the writer understands it, as far as the present analysis goes, it is probably the intention to compare stations of practically the same size. Although it might seem a difficult matter to establish a relative scale for plants of different capacity. I believe this phase could be worked out in a satisfactory and dependable way through a synthetical study. There will probably be times when it will be desirable to compare stations of different capacities regarding which the other operating conditions are very similar.

As is obvious, the question of power plant comparisons is, to a large extent, involved, and the authors are to be highly commended for the steps they have taken to overcome the apparent obstacles and make comparisons of practical and definite value.

**Charles S. Ruffner** (by letter): The power costs of two given plants will differ because of size, cost of labor, fuel and other supplies, the average use of maximum load or load factor, the relation of maximum demand to total capacity, investment, efficiency of management, and the degree of proper coördination of each unit of equipment as regards relative capacity and location. The paper of Messrs. Stott and Gorsuch attempts to

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compare power costs by eliminating or equating three of these variables, cost of labor, cost of fuel and load factor. with the obvious purpose of determining the last two, viz., efficiency of operation and efficiency of original design.

Like all comparative analyses of costs and efficiencies the problem is one containing so many variables as to make difficult a mathematical solution, and it has often been questioned whether the generalized results obtained by such studies justify the elaborate processes involved.

Comparative costs of generating electrical energy are, however, becoming of increasing importance. The determination of reasonable rates by regulating commissions raises the question of relative efficiency. The value of a water power, where such a separate value exists, involves the question of the financial economy of hydraulic generation over other available processes, and while the present paper relates to steam plants only, similar methods must be developed for making such comparisons of various types of generation. Large operating syndicates are in need of concrete methods of analyses for comparing the results obtained by the various plants under their supervision. The necessity of a comprehensive scheme of analyses for these purposes will outweigh the limitations of comparative methods such as those outlined in the paper.

The classification of accounts which comprises the larger portion of the paper is not essential to the scheme of analysis outlined. Central stations are generally operating under classifications recommended by the National Electric Light Association. or the American Electric Railway Association or prescribed by state commissions. These accounting systems segregate the operating cost at switchboard from other operating costs and subdivide this general group into station labor fuel, miscellaneous operating expenses and maintenance items similar to those provided in the paper. While the proposed classification has many novel features it is not suited to all sized plants, does not take into account the possibility of the steam plant being used for other than steam generation purposes, evidently overlooks the impracticability of separately segregating general and undistributed expenses belonging to power costs from other portions of the business and introduces terminology much at variance with established practise. Present central station accounting methods have been gradually developed after years of experimentation and after consideration of the joint needs of the operating manager, the accountant and the engineer and it is difficult to see what purpose will be accomplished by the changes contemplated. The accounts of any up-to-date electric utility permit separation into the items of Production Cost, Production Repair Cost and Investment Cost, the sum totals of which are used in the scheme of analysis, and will disclose the proportionate amount of expense burden applicable to these costs.

The most important feature of the plan outlined for compar-

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ing costs is the load factor. The effect of load factor upon the investment costs is not difficult of determination since these costs per unit are an inverse function of the use. Question may be raised, however, as to the basis of calculating what the investment charges really are.

Interest and profit are inseparably associated in "rate of return" and few investors or bankers would finance a power plant with the expectation of receiving only a five per cent rate of return on their investment. It is true that money is often borrowed at five per cent interest for short terms or for long periods where the security is gilt edge, that is, with a substantial equity. The owners of the equity, however, expect larger rates of return than five per cent, either through the payment of interest or dividends or appreciation in market prices of their holdings. The use by engineers of low interest rates on the entire investment in calculating annual costs has contributed to the low regard in which capital "planted" is held today.

Considerable difficulty must necessarily be encountered when attempting to determine the proper amount to be set aside annually to cover that portion of investment charge represented by depreciation. The work of prophecy is an exceedingly difficult task at which to maintain a reputation for accuracy and has developed attractions since the world began. The man putting up his money cares little whether the unit of equipment requires abandonment on account of wearing out, obsolescence or inadequacy. He desires the engineer to advise him with respect to proper annual reserve which in the long run will reproduce his investment. Data upon which to predict such calculations are very meager and confined to a few instances, possibly not representative of the group or class. The accuracy of such calculations, even for a class, can not accordingly be very great, and herein lies another reason for estimating the cost of money at higher than ordinary interest rates, to at least in part compensate for the hazard arising out of the lack of knowledge of the probable life of units of equipment. The Institute has much work cut out for it along this line.

The effect of load factor upon the cost of operation and repairs is, however, more involved. This relationship, it is stated in the paper by the authors, may be expressed by the empirical formula

$$Y = s \frac{y \sqrt[4]{x}}{\sqrt[4]{X}}$$

where $Y$ represents the cost in mills per kilowatt hour net output, $X$ the corresponding load factor expressed in per cent, and $y$ a constant for any curve. It is stated that "this law will hold between 15 per cent and 90 per cent load factors and is applicable for individual plants, but in comparing independent plants the cost of power in each plant should be reduced to a common load factor."

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It would be fortunate if this important relationship could be thus simply expressed and the entire problem of station economy reduced to an approximate formula. It is observed, however that the expression does not even generally fit the experience with which the writer is familiar. It does not account for variations in monthly costs with which the operator is interested and does not promise as great economies with better load factors as experience has proved are possible. Two typical instances, one condensing turbine operation and the other Corliss condensing engines, may be cited as illustrations, and are given below:

| Station A | | | Station B | | |
|---|---|---|---|---|---|
| Monthly load factor. | Actual mills per sb. kw-hr. | Calculated mills per sb. kw-hr. | Monthly load factor. | Actual mills per sb. kw-hr. | Calculated mills per sb. kw-hr. |
| 45 | 6.46 | 6.36 | 35 | 11.30 | 9.63 |
| 47 | 6.97 | 6.29 | 38 | 11.34 | 9.43 |
| 48 | 6.75 | 6.27 | 45 | 10.48 | 9.06 |
| 49 | 6.38 | 6.25 | 46 | 9.62 | 9.02 |
| 50 | 6.20 | 6.20 | 47 | 10.41 | 8.95 |
| 52 | 6.02 | 6.16 | 48 | 9.56 | 8.93 |
| 54 | 5.55 | 6.09 | 50 | 8.82 | 8.82 |
| 55 | 5.87 | 6.06 | 54 | 9.02 | 8.66 |
| 57 | 5.78 | 6.00 | | | |
| 60 | 5.42 | 5.93 | | | |

Station A is a medium-size plant of 30,000 kw. capacity. Station B is a small plant of 5500 kw. capacity. Both calculated costs are based upon the actual costs at a 50 per cent load factor. The choice of some other basis might have led to better closeness of fit of actual conditions and conditions assumed of formula, but would not have obviated the variations noted or spanned the maximum and minimum of the observed data.

An examination of the formula indicates why this is the case. The equation assumes a fixed relationship for all types of steam generation, makes no allowance for the operation of several units at different times or for the size of the equipment and its overload capacity. Assuming that the cost at 100 per cent load factor is unity, the formula fixes the cost at 20 per cent load factor at 1.47, a 50 per cent load factor at 1.19 a 60 per cent load factor at 1.14, etc. That important variations may be expected from the assumed standard is apparent from an inspection of the familiar economy curves of boilers, prime movers and generators. Various combinations of these factors are certain to effect changes in the resultant curve.

The cost sheet of the power plant at various load factors moreover, does not reflect merely the relation of input to output. It consists, especially in plants of limited capacity, of many items of cost fixed in their nature and independent of load factor or

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output. Certain labor and maintenance items, for example, may be expected to continue whether the plant is fully utilized or not. In small plants this constant quantity is of greater magnitude than in large plants and the effect on the cost at various loads is one of varying degree. All of these factors must be accounted for in any empirical formula designed to compare results of operation.

When the various items of power costs are separately scrutinized from month to month it is noted that each has its own basis of variation. Statistical units may be frequently developed to reduce these variables to more constant quantities and it is believed that this method of preserving data is the first step in the development of a cost formula. From a management standpoint increases in power costs are of particular interest because they are due partly to changes in the demand and load factor over which the management has little or no control and partly to direct additions to expense for which the responsibility can be directly localized. Both types of causes effect an increased cost per kilowatt-hour. The fuel cost which theoretically must be some function of the load factor will fall largely in the first class. The remaining items, labor supplies maintenance, etc., fall largely in the latter class and while a small proportion of the total is that part in which the greatest possibilities for economies in operation arise, and hence of the greatest interest.

A report form based upon a statistical comparison other than kilowatt-hour costs is used by one of the largest operating syndicates. The classification of accounts corresponds to that of the Public Service Commission of the state in which the plant is located. The data disclosed for the various items of steam and power plant costs are as follows:

STEAM GENERATION

| No. | Account. | General Unit | Specific Unit |
|---|---|---|---|
| 601 | Boiler plant superintendence | sb. kw-hr. | Per cent. of 602-616 |
| 602 | Boiler plant operating labor | " | Coal ton. |
| 603 | Coal and ash handling operating labor | " | Coal ton. |
| 604 | Water purification operating labor | " | 100 cu.ft. |
| 605 | Fuel for steam (Cost of fuel in storage) | " | Coal ton. |
| 606 | Water for steam | " | 100 cu.ft. |
| 607 | Water purification supplies | " | 100 cu.ft. |
| 608 | Boiler plant tools | " | Boiler h.p-hrs. |
| 609 | Boiler plant supplies and expenses | " | Boiler h.p-hrs. |
| 610 | Removal of ashes expense (haulage from plant) | " | Coal ton. |
| 611 | Maint. of boilers and boiler aux. equip. (labor) | " | Boiler h.p-hrs. |
| 612 | Maint. of boilers and boiler aux. equip. (sundries) | " | Boiler h.p-hrs. |
| 613 | Maint. of coal and ash handling equip. (labor) | " | Coal ton. |
| 614 | Maint. of coal and ash handling equip. (sundries) | " | Coal ton. |
| 615 | Maint. of water purification equip. (labor.) | " | 100 cu.ft. |
| 616 | Maint. of water purification equip. (sundries) | " | 100 cu.ft. |
| 617 | Maint. of boiler plant bldgs., fix. and grounds (labor) | " | Boiler h.p-hrs. |
| 618 | Maint. boiler plant bldgs., fix. and grounds (sundries) | " | Boiler h.p-hrs. |

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ELECTRICAL GENERATION

| No. | Account. | General Unit | Specific Unit |
|---|---|---|---|
| 626 | Prime mover plant superintendence | sb. kw-hr. | Per cent of 621-629, and 632-642. |
| 627 | Prime mover operating labor | " | kw. demand. |
| 628 | Prime mover plant elec. operating labor | " | kw. demand. |
| 629 | Prime mover plant mscl. operating labor | " | kw. demand. |
| 630 | Steam generated (proportion of cost) accts. 601-618 | " | kw. demand. |
| 631 | Steam purchased | " | kw. demand. |
| 632 | Prime mover plant lubricants | " | kw. demand. |
| 633 | Prime mover plant tools | " | kw. demand. |
| 634 | Prime mover plant supplies and expenses | " | kw. demand. |
| 635 | Maint. of prime mover (labor) | " | kw. demand. |
| 636 | Maint. of prime mover (sundries) | " | kw. demand. |
| 637 | Maint. of prime mover aux. equip. (labor) | " | kw. demand. |
| 638 | Maint. of prime mover aux. equip. (sundries) | " | kw. demand. |
| 639 | Maint. of generators and aux. gen. equip. (labor) | " | kw. demand. |
| 640 | Maint. of generators and aux. gen. equip. (sundries) | " | kw. demand. |
| 641 | Maint. of aux. electrical equip. (labor) | " | kw. demand. |
| 642 | Maint. of aux. electrical equip. (sundries) | " | kw. demand. |
| 643 | Maint. of prime mover plant bldgs., fix. and grounds (labor) | " | kw. demand. |
| 644 | Maint. of prime mover plant bldgs., fix. and grounds (sundries) | " | kw. demand. |
| 731 | Electric current exchanged (between plants) | " | kw. demand. |

For large plants these costs are subdivided in greater detail although the units of comparison are similar. The statements are also supplemented by statistics of demand, capacity, output, coal, water and lubricants. It will be noted that the electric generation costs are classified under both the kilowatt or demand unit and the kilowatt-hour or output unit. Some of these items vary directly with the demand; others respond to changes in output. The large majority of items, however, vary with the load factor and are affected by both demand and output. Were the plant operated at 100 per cent load factor by far the greater portion of the "steam generation" expense then would be an output cost. While operated at less than 100 per cent load factor standby losses are developed, a large portion of which are eliminated with better load factors. Labor costs develop even greater standby losses at low load factors, and these items alone serve to explain why better economies are possible, than the formula presented would anticipate.

The varying items comprising station operating cost are of too great importance to be merged into a general formula even when expressed as an equation of the fourth power, if the purpose in comparison for the sake of determining relative efficiency or possible future economy. If it is possible to develop a single formula which reflects in like manner two types of operation, it is believed that a segregation of the following four items is essential:

(a) Operating costs continuing irrespective of the output, such as labor, maintenance, etc., but affected by the demand.

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(b) Costs varying as some function of the load factor, such as fuel, labor, water, etc.
(c) Costs varying directly with the output.
(d) Overhead costs such as supervision.

Such a separation will not only provide the means for direct comparison of different plants but will give the separation of costs necessary to determine the charge to be borne by various services supplied by the same central station, such as traction and commercial lighting, and will serve as a basis for fixing the rate of charge to be made to customers under a demand and energy schedule. It also does not seem probable that fullest economy can be obtained in operation until those portions of cost which directly concern the management are separated from those costs which are dependent upon a varying public demand for service and hence without the control of the management.

**S. D. Sprong** (by letter): The following notes refer only to the paragraph entitled "Estimated Life of Apparatus", including Life Expectancy Table, of the paper by Messrs. H. G. Stott and W. S. Gorsuch.

I agree with the writer that estimating the life of apparatus is a highly speculative matter, but do not believe that all the figures given in the life expectancy table represent the results which have been obtained in first-class well designed power plants.

Between the years 1893 and 1898, a number of first-class steam driven power plants were designed or erected in the Greater City of New York. These plants were equipped with reciprocating engines, the majority of which are still in operation and apparently will continue to operate for years to come. It, therefore, seems that the total life of twelve years estimated for engines and condensers is far below what may actually be obtained in view of the number of engines now operating which are from 15 to 20 years of age. The same general statements apply to alternators for which the estimated life is stated as twelve years as practically all the large alternators installed in New York City beginning with 1897, or sixteen years ago, are still in operation.

Synchronous converters are given an estimated life of twenty years. A number of these machines have been in operation in New York City from about the year 1894, and a large number of the batteries now in use have been in service from 10 to 15 years. The author estimates ten years as the average life of the battery, but there are a large number of batteries now operating in New York considerably older than this, and which batteries are still in first class condition. In the early days the battery manufacturers were willing to guarantee the total maintenance of the battery for 6 per cent of the cost which, without considering interest, would mean a life of over sixteen years. The actual scrap value of lead in batteries will run from 10 per cent to 20 per cent of the original cost according to the condition of the

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plates. The average life of a battery depends almost entirely upon its number of discharges rather than its life in years. The vehicle battery may have to be replaced yearly if discharged daily, whereas a station battery under average operating conditions would probably not have the same number of discharges in thirty years.

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DISCUSSION ON "THE BEHAVIOR OF SYNCHRONOUS MOTORS DURING STARTING" (NEWBURY), "COMMUTATING POLE SATURATION IN DIRECT-CURRENT MACHINES" (STOKES), "CONSTANT VOLTAGE TRANSMISSION" (DWIGHT) AND "THE INDUSTRIAL USE OF SYNCHRONOUS MOTORS BY CENTRAL STATIONS" (PARKER), COOPERSTOWN, NEW YORK, JUNE 25, 1913. (SEE PROCEEDINGS FOR JUNE AND JULY, 1913).

*(Subject to final revision for the Transactions.)*

**William J. Foster:** The self-starting synchronous motor has one bad characteristic and that is the induced potential across the field terminals. It is something which exists in the nature of the apparatus. Of course, if we keep down the number of turns in the field winding, we always can help out in the matter of induced potential, but, as is stated by Mr. Newbury, it is not always convenient to do this. As a general rule, 125 volts has been regarded as standard, and we can design and wind the fields and insulate them so as to take care, ordinarily, of 125-volt windings, but when it comes to 250 volts it begins to be a serious matter. The insulation problem is serious. In such cases I have known of this scheme of short circuiting the field to have been the practical solution of the problem, but in general, as pointed out by the author, the short circuiting of the field detracts from the starting torque per input. That being the case, it is extremely desirable to excite at lower potential.

There is a particular use which can be made of the short circuited field that I have known to have been resorted to in a number of cases of motors that have an increasing torque from rest to synchronous speed and that is to short circuit the field when about two-thirds speed has been attained. By doing that the torque can somewhat be increased at the higher speed, before you reach the point where excitation can be applied.

I think there are many places where synchronous motors are now installed and some difficulty, perhaps, is experienced in starting up at the pulling in point, where by installing a resistance and short circuiting the field much better results can be obtained.

**August H. Kruesi:** I want to suggest that the author give us the number of slots per pole, the radial depth of air gap and the number of bars in the short-circuiting winding for both machines so that we can tell to what extent the performance depends upon the particular design of the machine tested.

**F. D. Newbury:** The number of armature slots per pole is twelve, and the radial depth of air gap 3/16 in. (4.76 mm.) The number of damper bars per pole is seven and the damper winding is of the same type as shown in Fig. 1. The armature slot pitch is 0.88 in. (22.35 mm.) and the damper slot pitch is 1.15 in. (29.2 mm.)

**H. M. Hobart:** Mr. Stokes's paper draws attention to one of the greatest difficulties in connection with the design of machines with commutating poles. The commutating pole certainly

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has been of very great service in improving the design of commutating machinery, but there are two sides to the matter and it has always seemed to me that it should not be used to any greater extent than is necessary for the accomplishment of the purpose for which it is put there. At its advent, designers used it to a very great extent and overdid the thing. The reasoning was that since with the commutating pole one could offset very large reactance voltages in the coil undergoing commutation, there was no need for any great subdivision of the commutator. It was considered that by having fewer segments and cheapening the construction of the commutator one could get as good results by neutralising the reactance voltage in the short circuited coil by appropriately designed commutating poles, but it soon became apparent that there would be a tremendous magnetic leakage from these small commutating poles to the large main poles. Some designers appreciated that, but they were in a small minority. Most designers made the commutating poles the full length of the machine, but as Mr. Stokes points out there is 200 or 300 per cent magnetic leakage under these circumstances, unless you are quite careful in the design of the machine.

I considered right from the beginning, that the use of the commutating pole should be as follows: to design the machine as well as you could, quite aside from the commutating pole, and then put in enough commutating pole to neutralize the amount of reactance voltage, which you ordinarily have in the machine, or as much of it as is necessary to insure good commutation. My experience has been that it has usually worked out admirably to have the commutating pole extend only a very short distance in a direction parallel to the shaft. Make it as short as possible for the requirements. One should follow the procedure of first designing the machine as good as possible, without any reference to the intention which you have in reserve of adding the commutating pole.

Designers have been tempted to employ high reactance voltages. If, for example, a machine were planned with a reactance of 4 volts in the short-circuited coil, it might require that the commutating pole should extend the full width of the machine. If, however, a better design had been employed and the reactance voltage had been limited to 2 volts, then the machine could have been fitted with commutating poles of only half as great a length. This would have resulted in reducing the magnetic leakage and in less obstruction to the circulation of air amongst the poles.

Even at this late date, although the commutating pole has been used extensively for 10 years, there is still great need to emphasize this viewpoint. I am interested to see that the matter is being reduced to quantitative constants that will be of great aid, I have no doubt, to the designer.

**F. D. Newbury**: My own experience with direct-current design has been largely second-hand, and the experience I have

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had has been in connection with alternating-current problems. It has always seemed to me that designers of direct-current machines have been more inclined to approach their problems through empirical methods than have designers of alternating-current machinery. Possibly this is due to their older experience, and the further distance they are away, in their methods from the simple fundamentals. That at least has seemed to be the tendency.

It is the greater pleasure therefore, to note that in the present paper the author has got down to fundamentals, has made up his formulas from the results of careful experiment, and has approached the subject from the scientific and physical standpoint rather than from the empirical.

While the paper is primarily of interest to the designer, it is, I think, also of interest to the men using direct-current apparatus. There is a direct and particular relation between the commutating pole saturation and the ability of a given machine to withstand heavy overloads. It is, of course, on overloads that the saturation of the commutating pole becomes apparent and the non-compensated reactance volts cause dangerous sparking. All direct-current machines, even the compensated type, will flash on dead short circuit where the current will be anything from 15 to 20 times full load current. I have had many tests made, which have borne out the statement that most machines will flash very seriously with currents from five to ten times full load current. Those machines in which the commutating poles have been liberally proportioned, and more important still as Mr. Hobart pointed out, machines in which the reactance volts have been made a minimum are the machines that will withstand the heaviest shocks and behave best on short circuits.

**J. M. Hipple**: In connection with Mr. Hobart's remarks, I call to mind a very extensive series of tests which showed clearly the advantage gained by the use of commutating poles. This test was made to determine if the commutating pole had any logical use in constant speed motor design. For some time its usefulness in adjustable speed motors had been conceded. A considerable number of representative motors of various makes were given endurance tests under these three conditions:

1. Full load and normal voltage.
2. Full load and 10 per cent below normal voltage.
3. Full load, normal voltage and 15 per cent increased speed by weakening the shunt field.

The motors tested were all of the non-commutating pole type and under condition (1) practically all gave good results, while under conditions (2) and (3) burning and blackening of the commutator developed in time. Similar tests on a series of commutating pole motors showed that under all three conditions, the commutator showed no signs of blackening or burning. Conditions (2) and (3) are not to be considered abnormal and must be provided for and the commutating pole when properly proportioned takes care of them perfectly.

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**H. M. Hobart**: Commutating poles are used as an antidote for certain troubles, and if the antidote is used to too great an extent it may cause a condition which is worse than that which it was designed to cure. That is the point.

**John M. Hipple**: There are two ways of considering the commutating pole, one as an antidote for commutation troubles and another as a prime factor in design. In my opinion it has a proper and very important field as a prime factor in design, just as in the noncommutating pole motor the saturated pole tip is often used as a prime factor.

**H. E. Stokes**: In regard to Mr. Hobart's remarks on the short interpoles, it seems to be the general experience that it is well to make them shorter than the armature, say about 50 or 60 per cent of the length of the armature, and that has the effect of permitting the heat to get away from the armatures as Mr. Hobart pointed out. Something can be done to get away from the leakage question by making the interpole shorter, as regards the armature, and lengthening it up near the frame.

In regard to what Mr. Newbury had to say about machines flashing-over, whether they are compensated or not, that is mostly due to the commutating pole flux lagging behind the reactance voltage which causes a flash-over which can scarcely be taken care of by the commutator form.

**F. D. Newbury**: Mr. Dwight's paper presents very clearly the advantages of synchronous condensers in holding constant voltage at the end of a long transmission line. There is one application which I understand has already been made where such a use of synchronous condensers was a necessity—the combination of a long line at high voltage and at high frequency so that operation with a light load at the receiving end made it absolutely necessary to install such synchronous condensers in order to hold the voltage down to normal, due primarily, of course, to the small generating capacity in comparison with the length of the line. In that case synchronous condensers of half the capacity of the generators at the generating station were installed. That is a special application of the general plan advanced by Mr. Dwight, and I am quite sure merely points the way to a more general use of such synchronous condensers. As Mr. Dwight points out, the use of such a large additional generator capacity can only be justified in the case of long lines, where the cost of the line will be a more important item in the total cost than the cost of the main and substation machinery.

Mr. Dwight refers to railway work as possibly the single exception to the general use of 60 cycles. I would point out that it is becoming more and more frequent to use 60 cycles for railway work employing 60-cycle synchronous converters. In the work of one of the larger manufacturing companies it has become very apparent that the use of synchronous converters, in the smaller sizes up to 1000 kw. has gradually shifted from 25 cycles to 60 cycles; whereas a few years ago the 500-kw., 25-cycle

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machine for example was built in large numbers, at the present time the 60-cycle converter is the more usual machine so that I think Mr. Dwight's single exception can be largely eliminated.

Mr. Dwight also has some misgivings as to the ability of such synchronous condensers operating at very low excitation for supplying leading current at no-load. I do not think any such fear need exist—practically any synchronous motor with a proper damper winding will hold up the voltage on poorly regulated systems at no load and very small excitation.

I ask Mr. Dwight if in his table on page 1370 the power factor at the generating station has been taken into account in determining the size and cost of the two schemes. In one case it is given as 99 per cent, while in the other it is given as 89 per cent. This difference of 10 per cent in the kv-a. capacity will increase the cost for the constant voltage method, but it is a minor point in connection with the total saving incident to the system.

**R. B. Williamson**: Mr. Newbury's paper is an exceedingly valuable and interesting one, and particularly so to those engaged in the design of self-starting synchronous motors. The various oscillograms give a complete picture of the actions that take place during the different stages of starting and make many things plain which, while known to exist were not heretofore clearly understood. Some of the features brought out by Mr. Newbury were touched on during the discussion of these motors at the meeting of the Institute held in April, 1912, in Pittsburgh, and the present paper clears up a number of points brought up at that time.

Mr. Newbury's conclusions drawn as they are from the very complete set of oscillograms leave little room for discussion. Some of the results obtained show that this class of motor is capable of performances at starting and pulling into synchronism much beyond the limits usually considered possible.

As regards starting from rest, the difference noted between the torque developed with the rotor winding open and closed is considerably less than most machines that have come under my notice. However, this is something that depends very largely on the design of the machine, and I agree with Mr. Newbury that except in cases where a very high starting torque is desired and where a high-resistance squirrel cage is used, it is possible and preferable to start with the field short-circuited through the rheostat though it may be necessary to open the field circuit later in order to prevent locking at half speed. I understand that the machines tested by Mr. Newbury had a laminated rotor spider; in machines having a caststeel or cast-iron spider, the voltage induced in the open field winding is considerably less than when the field structure is laminated throughout.

An important feature brought out is that it is not necessary to have two starting points, provided the most favorable procedure is adopted when starting; and the deductions drawn from the oscillograms show the methods of starting and amount of

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excitation best suited to different starting conditions. Before the influence of field excitation on the momentary rush of current at change-over was discovered, there was considerable trouble with these motors due to tripping circuit breakers. The oscillograms show plainly why this was so.

To many who have not experimented with this class of motor it will appear surprising that Mr. Newbury was able to pull loads practically equal to full load into synchronism. However, this is quite possible, although the large current required to do it must not be lost sight of, and in many cases this would preclude the use of the synchronous motor on such large starting load, unless of moderate size or operated on large systems where the current at starting was not objectionable. Fortunately, however, in many of the largest applications it is possible to reduce the pull-in torque required to a fraction of full load so that the starting current can be kept down. For example, air compressors can be unloaded, and centrifugal pumps can often be started with the discharge valve closed. Many of the early self-starting motors were made from parts originally designed for alternators, and did not give the best starting performance possible; but with careful design along the well-established lines of squirrel cage induction motors, starting performances comparing favorably with the induction motor can be obtained.

Mr. Newbury's paper deals with motors of the salient pole type and it may be of interest to mention some tests recently made on a small turbo-generator run as a three-phase self-starting motor. There has been, at least among some engineers, the opinion that the pulling in effect is due partly to the fact that the poles are sharply defined, and that a machine having a cynlindrical rotor without projecting poles and with a distributed field winding would be deficient in pull-in torque. Some tests were made with a small 125-kv-a., 2300-volt, 31.2-ampere, 3600-rev.per. min. turbo-generator having a smooth cylindrical rotor with 36 slots uniformly spaced around the circumference. The retaining wedges for the coils were of brass and made connections at each end with bronze end bells, thus forming a uniformly distributed squirrel-cage.

It was found that with the field circuit open, this machine started with 280 volts applied to the stator and came up to speed in 54 seconds while drawing a current of 67.8 amperes. That is, the motor started on approximately 12½ per cent voltage and 2.2 times full load current. The power factor at starting was between 45 and 50 per cent. With the field short-circuited, there was very little difference in the starting performance, the voltage and current being practically the same as before. Tests were also made with various resistances ranging from 0.9 ohm to 22.4 ohms in the field, but there was very little change noticeable in the starting performance.

Some tests were also made to determine the load that could be pulled in. With 1130 volts (about ½ voltage) applied to

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stator and with a field current of 19 amperes, it was possible to pull in a load of 32 kw. or about 25½ per cent of the rated output. The stator current just before synchronizing was 40 amperes or 1.28 times full load. Since the torque may be taken as approximately proportional to the square of the applied voltage, it is seen that this machine would probably pull in nearly full load if thrown over to full voltage. This was not tried in these tests on account of the loading arrangements not being suitable, but it is evident that the round rotor motor can pull in loads comparable with those handled by the salient pole machine.

**H. M. Hobart:** I share Mr. Williamson's views, and I am hoping that Mr. Newbury's paper will rather stir things up and make people take a little new courage in approaching the subject of the design of synchronous motors. It has gotten in to a terrible rut, it seems to me. This is partly due to the cause to which Mr. Williamson alluded. Matters have drifted into having the design of synchronous motors handled by the same departments that handle slow speed alternating-current generators. Any proposition to consider the design of synchronous motors along the lines of the design of induction motors has always been handicapped by the necessity of a change of hands, as to who should design it, and bring about the evolution of the synchronous motor into a decent machine. It is at present an absurd caricature of what it might be and the tantalizing part of it is that there are several perfectly serviceable methods ready and waiting to be used, but you cannot get anybody to look at these methods, or incorporate them in their designs, simply because they are following the old cut-and-dried methods, and everybody turns a deaf ear to any propositions for improvement.

Mr. Williamson alluded to some very interesting departures which he has had in hand and which it seems to me should offer much promise, but there are also other methods which would also serve to render the synchronous motor an admirable machine and make of it a machine which could be more widely used, for the reason that it will tend to decrease the price at which power can be provided to the consumer, in many cases, because you can run your synchronous motor with a leading power factor. That is a very important point indeed.

I believe that the synchronous motor can be used to great advantage on much smaller sizes than has heretofore been considered desirable, in sizes which will lap over into the field that has been generally held by common consent to belong to the induction motor. If only the synchronous motor could be designed by induction motor designers, working on the lines which have enabled them to see just what is needed for these starting and running-up conditions, the result would be for the good.

The induction motor has the fault that if you give it high starting torque, with the squirrel-cage variety, that will be accompanied by low efficiency and considerable heating. It must have high resistance in the squirrel-cage rotor, for the purpose

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of giving the starting torque required in many special cases. This is an inherent characteristic of the motor. But in the case of the synchronous motor you can, in a sense, leave it behind when you synchronize the machine and have a highly-efficient and cool-running machine for ordinary running, yet at the same time have a high starting torque, so that the synchronous motor, instead of being inferior in regard to its ability to have good starting torque characteristics, has an advantage over the induction motor in those respects. It ought to be associated in our minds as a characteristic of synchronous motors that they can be given *better* starting torque than induction motors, whereas we have just the other notion.

In reading over Mr. Dwight's paper, far too hurriedly, for so excellent a paper, it seems to me the nature of the results, and the careful calculations which he made, bring out much more strongly than they ever have heretofore been brought out the advantages to be derived from this use of synchronous condensers in connection with long distance transmission. The result is that the differences, expressed in percentages, are tremendous as regards extending the limitations. Why are we going to 100,000 and 150,000 volts? Because we have exhausted the possibilities of lower voltages in the matter of reaching out over wide areas and delivering energy at the limits of the system at a price which can compete with local plants. If, as Mr. Dwight's figures appear to show, you can, with a given voltage, if you operate on this principle, extend these limits 50 per cent, so that you can carry out at 100,000 volts, an undertaking in connection with which you would otherwise have to resort to 150,000 volts, you have just so far extended the limits, and when you are driven up to 150,000 volts, or higher, this further extension of the limits is still at hand.

As regards the amount of power transmitted, the distance to which it can be transmitted, and the price at which it can be delivered at a great distance, it would appear from Mr. Dwight's figures that the constant voltage method of working will lead to great extensions of the possibilities in connection with the electrical transmission of energy. It seems to me that the conclusions are very fairly and clearly stated, and that the paper is for this reason a very valuable one.

**Lee Hagood**: I have been very much interested in Mr. Dwight's paper. It struck me that the most interesting feature of it was that he could work out so many results and come to such valuable conclusions by such very simple methods.

A short time ago I was identified with the design of a system in which we were laying out a 110,000-volt transmission line, and our starting point which had to be settled was: what would be the size of our synchronous condensers. The necessity for this arose because our load was chiefly an inductive one, and we could not proceed with the design of the system until we settled upon the difference in voltage between the generating and receiving

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stations at full load. Until this was settled, we were unable to fix the voltages and taps for the transformers and the kv-a. ratings to give our generators and transformers. Another point of considerable importance was the size of conductor. As the transmission line was very long, it was important, on account of expense, to use as small a conductor as was consistent with good engineering. All of these points revolve around the question of voltage difference maintained between the generating and receiving stations, because the power-factor and efficiencies of the line have fixed relations depending upon the kilowatt load for a given voltage difference and line constants. The question of the size of synchronous condenser is dependent upon this and also upon the power factor of the load.

I note that Mr. Dwight does not take into consideration the charging current of the line. I think this can be neglected for lines under 60 000 volts, but I think for all long lines above this, it should be included.

(The lantern slides and explanations of them, included in Mr. Hagood's discussion, will notbe reproduced here, as they were used in connection with a paper presented before the Los Angeles and the San Francisco Sections, entitled *Operation of Transmission Systems*. It is published in the December 1913 PROCEEDINGS.)

**N. E. Funk**: Referring to Mr. Parkers paper, I wish to call attention to the fact that even though we consider raising the power factor from a low value to unity, which is the worst condition so far as cost is concerned that can be imposed upon a synchronous condenser installation the cost balance will still be on the right side of the ledger as the following table will show.

| Load. | P. F. of load | P. F. of Line | Syn. motor capacity. | Gen. capacity | Cost of gen. | Cost of motors | Cost per kw. of load | Savings per kw. of load |
|---|---|---|---|---|---|---|---|---|
| 100 | 80% | 80% | 0 | 137.5 | $10,312.50 | 0 | $103.125 | |
| 100 | 80% | 100% | 60 | 104.93 | 7,869.75 | $600 | 84.69 | $18.435 |
| 129 | 80% | 100% | 77.4 | 137.5 | 10,312.50 | 774 | 85.80 | 20.00 |
| 129 | 80% | 80% | 0 | 182.1 | 13,657.50 | 0 | 105.80 | |

The above table is based on a 10 per cent line drop in the first instance and the same line used in the other cases. Cost per kw., generators = $75, cost per kw., motors = $10. The first two lines show the saving in generator capacity by using synchronous motors. The last two lines show the increase cost of generators required without synchronous motors to load the generators in the first line with synchronous motors.

Mr. Parker says: "Where the synchronous quadrature demand can be made in excess of the lagging quadrature demand from induction motors it then becomes desirable to put inductance in series with the feeder thereby overcoming the drop due to the in-phase amperes operating in conjunction with the line

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resistance." By doing this the drop is decreased, but at the expense of a lower power factor, which will increase the kv-a. capacity of the generators faster than the decrease in drop decreases it. The idea is that where a transmission problem involves the use of synchronous machines to control power factor it is much better to favor the generating station as it is the most expensive part of the equipment.

**M. T. Crawford**: Mr. Dwight states that in commercial practice with short lines, constant voltage transmission is worth while merely on account of the improvement in service. In a system where the average load conditions are found, there are always a number of feeders supplying industrial power and railways in which a voltage variation of 10 per cent is within the limits of good service. For the remaining feeders supplying light and small power, automatic feeder regulators can be installed and operated at a much lower cost than the synchronous condenser installation for constant voltage operation. It might thus appear that where the lines are fairly short and no marked saving can be made by their increased carrying capacity separate automatic regulation might generally be more economical, especially as it avoids increasing the amount of apparatus and complication of the high-tension system.

**Henry W. Peck**: An idea which may be of interest occurs to me, viz., that possibly we can use synchronous motor exciting apparatus to greater advantage at the distributing end of some of our lines than at the generating station end. In Schenectady, where we purchase 40-cycle power and transform it to 60-cycle, we have several small machines in the generating station which we practically never use, and as soon as I return home I intend to look up the matter as to whether or not we can use these motor generator sets advantageously as synchronous condensers on some of our long feeders.

One line which I have particularly in mind supplies an amusement park about five miles (8 km.) out of the city, the line being about ten miles (16 km.) long. When the park is not being run we get reasonably good regulation on the line, but when the park is in operation we have a good many complaints regarding our service. I believe we could advantageously take some of our synchronous generating equipment and make better use for it at the end of the line. I realize in making this suggestion that the present machine would not be ideal for that service, but when you consider the scrap value of such a machine, which is all that you could get for it, it means the tying up of very little investment for the sake of this regulation. If this idea is not practicable and this plan will not apply I will be glad if some of the designing engineers will tell me why it will not apply.

**F. C. Caldwell:** What is the comparative effectiveness of synchronous machines, such as synchronous condensers, when running at full load, running at half load, and running light?

**F. D. Newbury:** I think that Mr. Caldwell's question can be best answered by reference to the familiar right-angle triangle

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of which one side represents the energy load carried by the motor in any particular case; the side at right angles to this, represents the leading wattless kv-a. supplied to the supply line; and the resultant of these two represents the total kv-a. load on the motor. If the energy and wattless loads are equal (and representing the total load by 100 per cent), each will be equal to 71 per cent. Thus, if these two functions were performed by separate motors, the two motors would require a combined capacity of 142 per cent. If the ratio of energy load to the total load were smaller—say, 60 per cent—the wattless component would be 80 per cent to load the motor up to 100 per cent. Thus 140 per cent "service" is obtained as compared with 142 per cent in the previous example. It will be found that the maximum service will be obtained from a given motor when the energy and wattless components are equal—in other words, when the energy load is 71 per cent of the total. This, of course, is the same as 71 per cent power factor.

**Burton McCollum**: Mr. Dwight points out in a very effective manner some of the advantages that accrue from the use of synchronous condensers in connection with constant voltage transmission, particularly the operating advantages, and he also cites some rather remarkable economies, particularly where he gives some comparative cost data, but I believe that in most cases these economies are largely apparent only.

In the second comparison for the 100-mile (160.9-km.) transmission line he makes a comparison on a 54,000-kw. transmission, and reduces the efficiency of transmission from 95 per cent to 91 per cent, but by so doing he is able to bring about an economy of something like 26 per cent in the initial installation. Now, if we figure the money value of the increased energy loss that results using the rather liberal line loss factor of 0.3., (the ratio of the average square to the maximum square) and taking one half a cent per kw-hr. for the value of the energy, we find it figures out at $27,500 a year as the value of the energy loss which is more than 10 per cent of the saving that results in the line construction.

A similar statement can be made in regard to the first comparison, although the results are somewhat less marked. This statement would of course apply to a steam plant transmission line rather than a water power transmission. In the case of the water power plant the value of the energy lost would be less, but the line loss factor would usually be larger which would partly offset the lower value of power.

I do not want to detract in any way from the importance of the paper by Mr. Dwight, because I regard it as an important development in engineering, but I feel that the advantages that are to be looked for are for the most part advantages in improved operating conditions rather than in increased economies.

**H. B. Dwight**: Mr. Parker's paper on the application of synchronous motors in the distribution of power in cities, shows

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that this type of apparatus produces desirable economies and improvements in operating conditions in this class of work. As he points out, the supply company is benefited rather than the customers, and accordingly the latter must be compensated for installing the more expensive synchronous machines. He suggests making compensation by charging for the kilovolt-amperes supplied, thus influencing each customer to operate at all times as closely as possible to 100 per cent power factor.

Although it is evident that compensation must be made to secure the installation of synchronous motors, there are two objections to the above method of charging for electric power, namely, that the kilovolt-amperes are very difficult to meter and that this method does not secure the best possible benefits from the synchronous motors according to the real needs of the supply company. The benefits may be of two kinds; first, reducing the kv-a. load on the generators, and second, reducing the cost of feeders by improving the voltage regulation. For the first, the synchronous motors should operate as strongly leading as possible at all times, but for reducing the necessary cost of feeders, which is often comparable to the cost of generators and which is also often increased by poor voltage regulation, adjustment of the synchronous motors is necessary. This is well accomplished by automatic regulators, as mentioned in Mr. Parker's paper. The saving in cost of feeders can also be made by installing a high-voltage transformer. Neither of these methods of operating the motors corresponds to keeping the customer's power factor at 100 per cent. It is accordingly better not to charge for the kilovolt-amperes, but to charge for the kilowatts, as usual, and to have a separate provision in the contract giving a bonus to the customer for operation of the motors either according to instructions from the company, or by automatic regulators.

Regarding the paper on constant-voltage transmission, Mr. Newbury, I believe, mentioned that for railway work the frequency of 60 cycles is being used to an increasing extent. This is true where alternating current is used to supply direct current railways, since the 60-cycle rotary converter is now becoming more popular. But for single-phase and three-phase railways, the frequency of 25 cycles is used, owing to the characteristics of the motors.

The same speaker asked if allowance had been made for the ten per cent difference in the power factor of the generators in the 200-mile (321.8-km.) line. The item was not written down in the comparison as it would amount to only about $20,000. A more important item is the cost of energy for extra line losses with the constant-voltage system, as mentioned by Mr. McCollum. For a water-power plant, this item is equal to the cost of machinery to supply the extra losses at peak load. At $50 per kw. this amounts to about $200,000 for the 100-mile (160.9 km.) line which Mr. McCollum took up. Against this item, there

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must be taken into account the two other items not put into the table because of their indefiniteness. These are the saving in the cost of land and the value of the improvement in service, and they balance fairly well the cost of power for extra losses. The purpose of the cost comparisons in the paper is to point out that for almost any installation it is worth while figuring up costs to see if synchronous condensers are not profitable.

The curves shown by Mr. Hagood were very interesting and I have just one small matter to bring out regarding them. The capacity of the synchronous condensers was plotted always as a straight line. You will notice in the chart, Fig. 5, of the constant-voltage paper, that the capacity of synchronous condensers required is a curved line, and its curvature puts a theoretical limit on the amount of power which can be sent over a transmission line. In the case considered of the 200-mile (321.8-km.) line, the limit is only about 25 per cent more than the amount of power assumed for full load. The curvature of that line is evidently worth figuring up in long distance work. It is a rather peculiar effect that there is this theoretical limit to the power capacity of a transmission line of a certain voltage, which cannot be overcome by synchronous condensers nor anything else.

**Lee Hagood**: I cannot prove these curves mathematically, but I have tried a number of them and found them all straight lines.

**H. B. Dwight**: I have no doubt that the points you have plotted, as you say, are correct, and as far as you have gone along the line, it is practically straight. But the indication in plotting a straight line is that unlimited power could be transmitted over the line if enough synchronous motors were added. The limit, however, is struck very soon by this theoretical consideration which will show up if you try to put 50 per cent more power over the transmission line. You would run into the limit with your calculations in the same way.

**Lee Hagood**: I do not agree with you.

**J. C. Lincoln**: I inquire of Mr. Newbury what the starting torque is when synchronizing on the three types of rotors shown on page 1266. The curve is interesting, and it appears that the starting torque of the rotor with the brass damper windings is at rather high resistance, which is much greater at any particular voltage than in the case of the starting torque at low resistance, and my question is, which is the type of rotor that will come in synchronism with the least amount of current? Is it the brass rotor or the low-resistance copper rotor?

**F. D. Newbury**: To answer Mr. Lincoln's question first; there are two entirely distinct actions to be considered—two entirely different sets of characteristics. The copper damper winding which shows the lowest torque at starting will of course have the lowest torque as long as the motor is operating as an induction motor. The torque at which a given motor will pull into synchronism depends on the torque that results in a certain

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slip. There is a limiting slip, that may be one per cent or two per cent beyond which the motor is incapable of pulling over from the highest induction motor speed into the true synchronous speed. Therefore the torque, that a given motor will pull in, will depend on the torque that can be pulled by the motor with a given slip. Therefore, the motor with the lowest resistance damper winding will carry the most load with this limiting slip, and consequently will pull into synchronism with the largest load. On the other hand the high resistance winding will develop the largest torque at the lowest speeds as in any induction motor.

**J. C. Lincoln**: If there was contained in the paper a complete speed-torque curve, would the torque of the lower resistance copper-wound rotor be greater or less at speeds just under synchronism than the torque of the higher resistance brass wound rotor? It is very evident from the curve shown in Fig. 9 that at low speeds the brass wound rotors have a very much higher torque than the low resistance copper wound rotors. It would seem to me that at the higher speeds, just under synchronism, that the lower resistance copper wound rotor would have a higher torque than the higher resistance brass wound rotor, and therefore that a synchronous motor provided with a lower resistance copper wound rotor would pull into synchronism a larger load than the high resistance brass-wound rotor. I would like to ask the author of the paper if that is the case.

**F. D. Newbury**: The torque of the low-resistance rotor would be greatest at the highest speed at which the motor operates as an induction motor and will pull into synchronous speed.

**J. C. Lincoln**: That would amount to the same thing.

**F. D. Newbury**: Mr. Williamson spoke of the paper on the synchronous motor which was presented at the Pittsburgh meeting at the Institute last year. The admirable paper by Mr. Fechheimer was the starting-point of my own paper, since at that meeting the discussion was not at all favorable to starting with the field circuit closed. It may not indicate any change in the opinion of the members present, but simply indicate a change in audience, that the sentiment expressed at this meeting has been in the opposite direction.

As Mr. Williamson pointed out, I think the tests show that two starting voltages are not necessary, but I would qualify that in this way—that they are not necessary provided proper adjustments are made, but proper adjustments always mean careful and skilful attention, so that the two starting taps are used and are justified for the larger motors, where the consequences of wrong operation would be quite serious.

Mr. Hobart has regretted the lack of attention that has been given to the wound-rotor distributed type of synchronous motor. I think that it is more a lack of results than lack of attention and the reason for the lack of results is more fundamental than a difference of engineering department organization as Mr. Hobart

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suggested. The real reason is brought out by the difference in the magnetizing current required by a well-designed induction motor and well-designed synchronous motor. In an induction motor the magnetizing current is roughly 30 to 40 per cent of the armature current. In the synchronous motor the magnetizing ampere turns should be at least one and a half to two times the armature ampere turns. In order to obtain the necessary exciting ampere turns on a wound rotor synchronous motor a much larger rotor is required than for the salient pole type of synchronous motor or the round rotor type of induction motor. There is a good engineering reason therefore, for the practically exclusive use of the salient pole type. The same conclusion is reached by a comparison of the weights and costs of salient pole and round rotor types of alternators. I think it is well known that the round rotor type of alternator ordinarily used for turbo-generators means a larger machine and a more expensive machine than the salient pole type and the round rotor type is used because it is the only type sufficiently strong mechanically. The same point was well borne out by comparisons recently made on some 10,000-kilovolt-ampere, 600-rev. per min. water wheel generators, where the cost of the salient pole type was found to be approximately 50 per cent less than the round rotor type.

**M. O. Dell Plain:** I believe that the possible advantage to be gained by the average central station through a general use of synchronous motors instead of induction motors on their lines is largely offset by the greatly increased number of motor trouble complaints.

The advantage to be gained by the consumer is a very material one in cases where the central station penalizes a low power factor. This advantage, however, is also offset if the current charge is based directly on the demand. In such cases the present lack of a suitable demand meter results in considering the highest phase kv-a. reading as being the actual demand, and an unbalanced load being the usual condition, the synchronous polyphase load does not produce its fullest effect in lowering the actual charge.

The development of a reliable and inexpensive kilovolt-ampere demand meter would probably eliminate this objection.

**Henry W. Peck:** I have made a memorandum of two or three points which I will answer. The quality of the service is oftentimes more important than a very slight advantage in maintaining unity power factor at the station. It is not for the sake of the power factor primarily, that Mr. Parker suggests the use of synchronous condensers, but to maintain the service which we are giving to our customers.

Another suggestion was made that the synchronous condenser was in competition with the high-tension transformer. An operating man does not like to see his system separated into different voltages, 2300 volts on one part, 6600 volts on another part, and 13,000 volts on another part. From the opera-

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ting point of view it is much simpler to have the synchronous condenser than to step up certain portions of the line and have a great variety of transformers which you must carry in stock so as to be able to supply your customers with these transformers when they want them.

Referring to Mr. Dell Plain's remarks, it is manifestly impossible to put a synchronous motor in every and any installation regardless of the character of the plant and the man who is running it. In the case cited by Mr. Parker where they use the synchronous motors for pumping, refrigerating plants and similar purposes, they have operating men who are certainly of as high a class as any men we have in our own stations and who can be trained to operate the synchronous motors satisfactorily.

We must consider the economy of such an installation from the point of view of both the customer and the company. The customer must decide if the saving, due to the lower rate for power, is sufficient to warrant him in installing these appliances in his power plant, granting that they are not quite as simple and convenient as the induction motor. The company must decide if the saving and improved service incident to the installation of these appliances are worth the expense represented by the decreased rate for power and by the assumption of such part of the first cost of the machine as is represented by the excess capacity required to handle the wattless load.

As regards metering the kilovolt-amperes, I know that it has been done in one installation which was put in under Mr. Parker's direction, using two meters, a graphic voltmeter and a graphic ammeter. The installation in which this meter was placed was of 600-h.p. capacity, and the cost of these meters, while prohibitive on smaller installations, was by no means prohibitive for one of such large size. If the phase voltages were perfectly balanced there would be no difference in the current in the different legs. Measurements were taken at this installation and it was found that the difference in voltage and current in the different legs was negligible.

**N. E. Funk**: I did not mean to leave the impression that poor service was to be furnished so that the power station might enjoy the benefits of a high power factor, by any means. What I meant to convey was, that it was the best policy to attempt to get unity power factor rather than leading power factor which is as bad in so far as generator capacity is concerned as a lagging power factor. In following out this manner of design it is not necessary for the voltage at the receiving end of the line to vary any more than if the voltage were the same at both ends. There are various means of correcting voltage beside that of synchronous condensers, and if it is not possible to favor the generating station and get the proper voltage at the receiver this receiver voltage may be corrected by, say induction regulators and the synchronous motors used to annul the lagging component of the load. The thing I had in mind most particularly was the

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fact that it was better policy, on account of favoring the generating station and apparatus, which is the most expensive part of the system, to strive toward obtaining unity power factor on the generating station rather than calculating the line for a given voltage at the receiving end and allowing the power factor at the generating station to come what it may.

**C. P. Steinmetz:** The two papers on synchronous motors are very interesting to me, as they give much additional information regarding the usefulness of the synchronous motor as an element of the electrical system, particularly Mr. Newbury's paper with regard to the starting characteristics of the synchronous motor. Synchronous motors, synchronous converters, and synchronous condensers have now been used extensively for over 20 years, and their use is very rapidly increasing. Most of these machines are self-starting, starting from rest with their own power, but still I believe there are a few engineers who doubt the self-starting characteristics of the synchronous motor and consider this as the main disadvantage of the synchronous motor.

The fact is, as brought out by these papers, that the modern synchronous motor, and also its prototypes, are very well able to start from rest and run up to speed and carry considerable load up to speed. They, indeed, take a large current in starting and during acceleration, about as much as the large high efficient induction motors. The induction motor has never been questioned as to its ability in starting; but the synchronous motor is fully as well self-starting and sometimes it takes more current and sometimes less current than the squirrel-cage induction motor, as, indeed, it is an induction motor. It differs in these starting characteristics from the standpoint of the well-known squirrel-cage induction motor of large size only in the proportioning of the parts. The starting characteristics of the induction motors, have been limited by the proportioning of the parts required for getting efficient running, mainly the purpose of getting high efficiency, high power factor, or low exciting current.

These limitations are not questioned in the induction motor characteristics of the synchronous motor, because the synchronous motor is not expected to operate at speed as an induction motor. Therefore, whatever power factor and efficiency it might have when running at speed as induction motor is entirely immaterial, and therefore in proportioning the induction motor parts of the synchronous motor we are more unrestricted, in choosing those proportions which are capable of giving good starting characteristics, than we are in the large induction motor. That means in many cases it is possible to give to the synchronous motor better starting characteristics than to a large squirrel-cage induction motor. I pointed out some of these things in a previous discussion, for instance, that in the synchronous motor we may have, considering it as an induction motor, an exciting

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current of 100 per cent or more without its having any detrimental effect. In the induction motor, obviously such an exciting current would make it commercially inoperative, the reason being, at that time, under the conditions where the synchronous motor acts as an induction motor in starting, the energy current for acceleration is so large and the impedance current is so large that the exciting current does not cut any figures. It is negligible, no matter how much it would be in percentage compared with full load current.

The main differences in the proportioning of the induction motor part of the synchronous motor compared with the induction motor are three. First, the synchronous motor does not have uniform magnetic reluctance in all directions of the rotor, it is minimum in the direction of the field poles, and maximum at right angles thereto while the induction motor has uniform reluctance all around. This is a disadvantage in regard to the starting of the synchronous motor as an induction motor, since it tends to a lack of uniformity of the torque with the relative position, and thereby also tends to low torque points, that is to a tendency of sticking, as it is called, at intermediate speeds, more particularly at half synchronism. Second, the synchronous motor has a very large air gap compared to the air gap used in the induction motor. The induction motor, to get good power factor, low exciting current, must have as small air gap as mechanical construction permits. In the case of the synchronous motor the power factor and the running on light current do not depend on the length of the air gap. Therefore the air gap, in the case of the synchronous motor, is chosen in accordance with very conservative mechanical and other considerations. The large air gap has an advantage in starting in so far as it tends to give a uniformity of torque. Third, the secondary winding of the synchronous motor, compared with that of the induction motor, is of much higher resistance, which again is an advantage in starting so you see of the three main characteristic differences in the proportioning of the induction motor part of the synchronous motor one is against but the other two are in favor of high-starting torque and the result is that the synchronous motor really starts better than a large high efficiency squirrel-cage induction motor.

The oscillograms shown in Mr. Newbury's paper are extremely interesting in giving the starting characteristics, but from these oscillograms you can see there are many other things which the limitation of space did not allow Mr. Newbury to show. If you look at them you see this more particularly, in the case of the oscillograms of a current, the amplitude of the current, the periodic rise and fall. You see the meaning of that—it is due to the varying magnetic reluctance with the position; maximum current corresponds to maximum reluctance, minimum current to minimum reluctance. Hence the distance from current maximum to current maximum corresponds to the dis-

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tance moved by the rotor from one maximum reluctance point to another maximum reluctance point, which means the distance of half a field pole or multiples thereof, or the slip of half a field pole or multiples thereof. That means the space moved through but the frequency of the oscillograms gives the time, and therefore you see from these oscillograms that you can get, from the distance moved by the rotor and the time of motion, the speed-time curve during acceleration, and from the speed-time curve you get the acceleration-time curve, and therefore since acceleration gives you the torque, relatively, or when considering the momentum of the moving mass, then absolutely, you get the torque-speed curve. That means a variation of the torque of the machine from standstill up to synchronism. All the characteristic curves of motion you get from these oscillograms, curves which in the induction motor are difficult to get, because in the induction motor the speed range near maximum torque, is unstable, and characteristics of that range can be derived mainly by connecting the motor with a generator which feeds a direct current motor connected to constant speed shafting and varying the field excitation of the motor which checks the output. This is well known and has many times been described, and in this way you can hold the induction motor at any point of speed, stable or unstable, above or below synchronism, and you can get the complete torque characteristics. The oscillograms of the synchronous motor permit you to arrive at a very definite understanding of the speed-torque characteristics, which in the induction motor you might get, possibly, an exploring winding on the squirrel-cage.

Looking at these oscillograms, you see a number of characteristics which are incidentally mentioned. If you take curve, Fig. 2, at the end of the first oscillogram, you see a number of waves with a high and low amplitude alternating for a considerable number of periods there. Apparently the speed was practically constant, which meant a low torque point there, where the motor accelerated slowly, because after a considerable number of cycles there was no acceleration or little acceleration. That apparently corresponds to one-quarter synchronous speed, and later on at about two-thirds the distance of the second curve from the bottom of the page, there was a very large number of cycles where the amplitude is constant, where the machine moved from maximum reluctance point to maximum reluctance point, during one cycle or during half a cycle. During half a cycle it progressed half a field pole. That apparently is half synchronous speed where it tends to drop off a little. The next curve is still exaggerated, but much less prominent at the three-quarter synchronous point, so that if you would construct from the oscillogram the speed-torque characteristic, you would probably be required to introduce a considerable drop in the torque at half synchronism a moderate drop of torque at one-quarter synchronism, and a further moderate drop of torque at

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three-quarters synchronism. This is at the low voltage starting. At higher voltage starting that phenomenon is not so marked, but these oscillograms allow you to study the acceleration curve of the synchronous motor much more closely and control it much better than in the case of the induction motors, where it is more difficult to determine all these characteristics of intermediate speed. We thus see that, as an engineering problem, when it is necessary to provide high efficiency synchronous motors with good starting characteristics what we have really is a much more simple problem than in the case of the high efficiency induction motor, and in my opinion the large synchronous motor is really one of the most important, and most useful elements of the electric system, more so than the induction motor, because instead of spoiling the power factor it may be made to improve the power factor, and instead of interfering with the regulation, making the voltage vary more with the change of load, it controls, or permits the control of the voltage, or acts automatically without any control, by establishing a fixed voltage point due to its excitation. The synchronous motor tends to hold the voltage more nearly constant than the non-inductive load. Many engineers do not yet realize the usefulness and value of a synchronous machine as an element in the electrical system, and therefore I very much appreciate these papers, since they give additional information and undoubtedly will tend to give the synchronous motor a still wider application than it has today. The synchronous motor will naturally include the synchronous converter and the synchronous condenser.

**W. L. Merrill**: I desire to ask Dr. Steinmetz a question in connection with his discussion on synchronous motors, and that is, why he compared the large synchronous condensers or synchronous motors with squirrel-cage induction motors. It has been my experience in such applications where the question has arisen as to whether synchronous motors or induction motors should be used the squirrel cage motor would not even be considered; and it has been the custom always to supply wound rotor collector-ring type of motors in the majority of cases where practically any starting requirements were to be met. In some cases, however, where synchronous motors have been installed to do the work that is successfully being done by wound rotor motors, the operation of the synchronous motors compares favorably with the operation of a fuse after it is blown. I see no reason for comparing the synchronous motor with the squirrel cage induction motor for ordinary industrial applications.

**R. B. Williamson**: In regard to the point brought up by Mr. Newbury about the wound-rotor type of motor, my idea was not to recommend that type of motor in preference to the salient pole type. The experiment was tried simply to find out if that sort of motor could be started up equally well. Motors of this type might occasionally be used for high speed work. For ordinary service at moderate speeds they would have no material advantage and would be larger for a given output.

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**F. D. Newbury:** I wish to thank Dr. Steinmetz for his contribution to the discussion particularly, because his discussion brought out a number of points I hoped would be brought out; and I am free to confess that they were not included in the paper for other reasons than lack of space and time, as Dr. Steinmetz was kind enough to suggest.

There is one point in particular I have not been able to understand myself; possibly Dr. Steinmetz can explain it either now or after he has studied the matter a little. Figs. 28 and 29 show exactly the same conditions but there is a very marked difference in the amplitude of the armature current and field current changes.

**C. P. Steinmetz:** I wish to think the matter over a little more and cannot give an answer now but in regard to the former question, as to why I compared the synchronous motor with the squirrel-cage induction motor, the reason was that, when the synchronous motor starts, it starts as a squirrel-cage induction motor, since it is provided with a squirrel-cage, so we would naturally compare that with the squirrel-cage induction motor.

We all realize that there are very many motor applications where we need frequent starting at heavy torque and where we therefore use the collector-ring induction motor. These applications naturally would not, as a rule, be met by the synchronous motor but in the majority of cases the squirrel-cage induction motor is used and therefore I compared that motor with the synchronous motor. It does not mean that we can use a synchronous motor in every place. The induction motor with collector rings and rheostat armature control has its legitimate and very important field. We may say that since the synchronous motor starts as an induction motor instead of providing a squirrel-cage, a regular winding could be used with a rheostat and improve the starting of the synchronous motor and such was the point I made.

I remember the first big synchronous motor with which I had anything to do, that was in 1893, somewhere on the Pacific coast. The motor is still running. It had a three-phase pole face winding, each winding brought out to a switch, in which a rheostat was connected for starting, but that has never been done since, because there was no need for this complication; and in all the conditions where the synchronous motor was used it was considered alright to start as a high resistance squirrel-cage motor. That might possibly be done in the case of the synchronous motor by giving it collector rings and the wire wound induction motor winding. The objection to that is it means a winding which is used only in starting not in running, and that is a complication. If the winding is simple, as in the case of the squirrel-cage motor, which incidentally acts as an amortisseur winding,—a damper winding when running at synchronism, —then it is favorable, but it is hardly justifiable in most cases, to go to the complication of an external rheostat, but rather to

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use an induction motor with collector rings and rheostat, except in those cases, which may occur, where the synchronous motor is decidedly preferable. I do not recall any cases like this.

**J. C. Lincoln**: I would like to ask what is Mr. Newbury's experience with reference to the call for high-starting torque at low speeds and high-starting torque at near synchronous speeds. It happens my experience has been only where we had trouble when it was due to the fact that we had to have pretty high speeds near synchronism, but judging from the paper, and from the curves which are very instructive, I would infer Mr. Newbury's experience has been in cases where high torque was required in starting, and I ask what his experience is as to the ordinary requirements of starting torque, whether a high starting torque is required at starting or near synchronous speed?

**F. D. Newbury**: Whether the required starting torque is greatest at standstill or synchronous speed depends on the application. The majority of synchronous motors is used in motor generator sets where the largest torque is required at standstill. This may be considerable, as much as 50 per cent, in some cases, of full load torque. In the case of pumps and fans and air compressors, the highest torque is usually required near synchronous speed. In the case of fans it is very hard to shut off the air supply sufficiently so that the torque at full speed is not very near the full load torque of the motor. In the case of pumps where a by-pass can be used, the torque at synchronous speed is considerably reduced. In the case of air compressors, the bulk of the trouble has been at pull-in, and I imagine the absence of trouble in many cases has been due to the fact that the motor was pulled in on full voltage and not starting voltage. Probably the bulk of the synchronous motors have been used for motor generators sets, where the starting torque is the greatest, so that quantitatively the bulk of the trouble has been at standstill.

**J. C. Lincoln**: With a motor-generator set, would you use a low-resistance winding on the motor?

**F. D. Newbury**: Not necessarily. Many and perhaps the majority are now built with the brass or high-resistance squirrel-cage windings, illustrating the point Mr. Hobart and Dr. Steinmetz made, that it is possible to obtain the good starting performance of the high resistance secondary with the synchronous motor while it is not possible with the squirrel-cage induction motor. With steam or water—driven generators now generally used there is little necessity for low resistance amortisseur windings for prevention of hunting.

**H. H. Dewey**: Mr. Newbury implied that in the case of large, slow-speed synchronous motors, having a large number of poles, it is a difficult matter to obtain high torque during synchronism. Do I understand that it is harder to obtain it with a machine of this kind than with a high speed machine having a smaller number of poles, and if so, to what does he attribute the difference?

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**F. D. Newbury:** It is decidedly more difficult to get high starting torque at pull in, as expressed in percentage of motor output, with the larger number of poles, and in the case of slow motors for air compressors the figure which has been more or less standardized by the compressor manufacturer's requirements, and also by tests, is about 15 per cent; that is, the motors will develop 15 per cent of their normal torque at synchronous speed. I have one installation in mind where they would just pull in, and the tests on the test floor show just about 15 per cent pull in torque. With slow-speed, two,—four—and six-pole motors, used for fans, it is not difficult to pull in at practically full load torque, if you disregard the starting torque and current. The reason for this difference is rather intimately connected with the proportions of the two machines.

**H. M. Hobart:** For a long time salient stator poles were used for very high speed generators, but now I think there is a fairly universal agreement that the windings should be distributed, although it is only comparatively recently that there was any general agreement on that point. Previously the salient pole was strongly advocated for even very high speeds. I feel that there should be a closer analysis of the differences in the construction and of the respective fields of usefulness of synchronous motors and induction motors. If the synchronous motor is to be developed on progressive lines the work must be entrusted to those who are accustomed to induction motor design.

**J. H. Wilson:** The question has been brought up of the pulling-in effect with a high resistance motor. I may mention two cases I had recently to do with, where a 2400-h.p. synchronous motor was connected to some grinding stones for grinding pulp. The grinder in question was of a comparatively new type, where the wood is piled in the hopper, twelve cords of wood pressing on the stones at all times. This particular motor had a high resistance it had a squirrel-cage winding. I have no way of finding out what the pull-in torque was, but it must have been considerable, because there was always a large amount of wood pressing down on the stone, each stone taking about 1200 h.p. That motor would start up on $1\frac{3}{4}$ to 2 per cent full load current on half the line voltage, and seemed to pull into step without trouble, so that the high resistance winding at or near synchronism must have given fairly high torque.

**C. P. Steinmetz:** Regarding the pull-in torque, I wish to draw attention to the necessity of some further study of this matter. The phenomenon in the synchronous motor pulling in to synchronism is not fully realized by all engineers. It is really not so much a question of the load which is to be pulled in but a question of momentum. A synchronous motor may have difficulty in pulling into synchronism while accelerating without any load, while it may pull in nicely without any difficulty at full load, because when pulling in it means it has to jump from the slip given by the induction motor into synchronism, and in

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that very short period it has to accelerate the momentum. The acceleration of the momentum is usually very much poorer than the actual load, so that you will find, when studying the pulling in of a synchronous motor, especially a high-speed motor connected to high-momentum apparatus, that the question of load or low load makes practically no difference, or very little difference. What we have to consider in the pulling-in characteristic of the synchronous motor is the momentum which has to be pulled into step, much more than the actual drag or torque.

**F. D. Newbury**: I do not wish to leave the discussion of round type versus salient type motors where it stands. There is not as much difference between Mr. Williamson and myself as might appear. I still hold to the point that it is a question of cost, and that is a hard question to overcome unless you can overcome it in the direction of a reduction of cost. I do not see how, from theoretical considerations, you can do that. Maybe I am mistaken but I cannot see it.

There are others, notably Mr. Foster, who have had experience along these lines, and I would like to know from him and others, whether their experience has been the same as mine; that the salient pole type for a given output can be built more cheaply than the round rotor type?

I am entirely in agreement with what Mr. Williamson said in regard to the performance of the round rotor type. There is nothing against its performance; in fact, it has very decided advantages, as Mr. Williamson pointed out; there is uniformity of reluctance so that there is a uniformity of torque in the rotor; the starting performance of the phase-wound induction motor can be obtained by inserting resistance in the external exciting circuit; other decided advantages have led designers to investigate it thoroughly. If my conclusions are wrong, I would be glad to be corrected.

**Wm. J. Foster:** My experience agrees entirely with Mr. Newbury. That matter has been investigated in a number of cases during my experience of 20 years or more. I think the first synchronous motor I had anything to do with was built with pole faces 85 or 90 per cent of the pole arc, as against the ordinary 65 per cent of the generator. Much of the investigation made along that line, with regard to the design of the synchronous motor, is based on using stock parts of induction motors, since we have the benefit of the cheaper production, due to stock parts, and can easily make, the nesessary modifications in the rotor, with the increased air gap, etc. It has been my experience that we have never been able to work out that type of motor in competition with the salient pole in any size in which synchronous motors are called for. In very small motors, it is often a profitable thing, because there is not demand enough to warrant the development of an entire new salient pole machine. Hence the synchronous motor can be best built from standard induction motor parts in very small sizes.

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As to the matter of the characteristics, I am sorry I have not exact data on the subject, but as far as my experience goes it has been in favor of the round rotor, that is, in returns that one gets for the input.

**H. M. Hobart:** People are usually willing to pay more for a good thing than for a bad thing, if only they can get the good thing.

**W. J. Foster:** I want to know in what respect it is a good thing as compared with the present motor. Why do you call one good and the other bad?

**H. M. Hobart:** I call it good because it starts with high torque and runs rapidly up to synchronism with good torque all the way through. These are not characteristics of synchronous motors as at present designed.

**Wm. J. Foster:** I have built and operated a number of motors of the wound rotor type, but I cannot agree with that statement. It is a question of how to adjust things with relation to the torque, and that is a serious drawback in the synchronous motor. It is right there where investigation has been going on quite actively in the last two or three years as to how to increase the torque.

**R. B. Williamson:** It seems to me the only reason for building synchronous motors with round rotors is the same reason for which we build generators with round rotors. It is a question of speed. To design a motor for, say, 3600 rev. per min. we would have to use a mechanical construction the same as for a turbo-generator; but for ordinary speeds where we would use a salient pole construction for a generator I should say by all means to use it for the synchronous motor. I do not think there are any great differences in the characteristics; the only thing I had in mind was the question of overcoming the mechanical difficulties at high speed.

**W. L. Merrill:** The principal point I wanted to bring out by asking Mr. Steinmetz the question I did is that the author of one of the papers appeared to be advocating loading up the central station lines with synchronous motors to the value of 40 or 60 per cent of their total load. My experience in industrial work is that possibly one or two per cent of the industrial applications of motors, with the present type of synchronous motor which we have, could be handled by synchronous motors, and I was afraid from the glowing comparison which Dr. Steinmetz made of the synchronous motor and induction motor that the impression might be gained that they were interchangeable, when as a matter of fact in the sizes which he was discussing no one would consider the question of a squirrel-cage motor any way. If we could get large synchronous motors, involving the characteristics of the form wound induction motors, it would not only be possible, but probable, that the central stations could go to 40 per cent of the total loads with synchronous apparatus.

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**Wm. J. Foster:** I wish to say in connection with the point brought up by Mr. Hobart that if you put in an external resistance with a definite wound rotor, and make use of external resistances, you get excellent results, as far as starting torque goes. You can then cut out the external resistance and switch the excitation on two phases of the rotor winding, leaving the third phase idle, or use one phase against the other two for excitation.

**H. M. Hobart:** In my first remarks I said there were various ways of improving the motors which were quite available and valuable, but that no one wanted to use them, but I did not go into the question of what those ways were. They related to this question of getting a high torque not only at the moment of starting, but a high torque right straight through into synchronism. I did not feel that it devolved on me to go into the details of these methods on this occasion since I have already published descriptions* of them. It is an interesting field to which little attention has been given. These methods will be widely used in the future. At present they are opposed in accordance with those general principles always acting when new ideas of value are first brought to attention.

**C. P. Steinmetz:** I do not think I am prepared to discuss off-hand the last subject which was brought up. We all realize what we have in the synchronous motor is the induction motor start, and also in the starting of the squirrel-cage, as squirrel-cage that is, high resistance in starting and decreasing resistance to a very low resistance at running, and that decrease should be as simple as possible.

In regard to the difference between the definite pole rotor and the uniform reluctance rotor, the main differences in my mind are that the definite pole rotor gives a less uniform starting torque, and if in starting we must consider the momentum torque, the definite pole rotor is inferior in starting, other things being the same, than is the uniform reluctance rotor. Furthermore, the definite pole rotor shows a drop in torque at fractions of synchronism, a certain amount at half synchronism, and less at quarter synchronism, more than the uniform reluctance rotor, which latter very often does not show a drop in the torque curve at all. On the other hand, the definite pole rotor drops into step easier, because it has that additional torque, the tendency of the magnetic lock, therefore in dropping into synchronism the definite pole rotor has the advantage.

At the moment of starting, the synchronous motor of today has ample torque to start any load which it will carry. However, the stopping off at half speed has been a very decided disadvantage in former times in the synchronous motor, but with the introduction of the fairly well distributed squirrel-cage winding, even with the winding local only through a wide field pole,

*See pp. 202 to 212 of "Design of Polyphase Generators and Motors" by H. M. Hobart.

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that difficulty has practically vanished, so that as it stands today, on the average there is very little to choose between the definite pole rotor, and the uniform reluctance rotor. You cannot say they are exactly alike, the one is better in pulling in and the other is better in acceleration, but after all, that is a question of the nature of the load, and also a question as to how much the one advantage or the other is worth under the greater cost of the construction, or whether it is not worth anything at all. It is really like most engineering problems, an economic question between the engineering design and the requirements of service, and the cost of the apparatus; but in the last five or ten years the advantage in development has been largely in improving the starting condition and the fraction synchronous condition, that is, reducing and eliminating the disadvantage of the definite pole construction, so that today the definite pole construction really has practically no disadvantage as a synchronous motor over the uniform reluctance type. Today indeed in the synchronous motor, that field in which there is the least known or available in the literature, are the phenomena of pulling into step, and as you have heard from Mr. Foster a large amount of investigating work is being carried on in this direction, and I hope Mr. Foster will be able, at some of the future meetings, to give us some additional information of the phenomena occurring in the synchronous motor in that range of speed where it is not an induction motor any more, and where it is not yet a synchronous motor.

**C. J. Fechheimer** (by letter): The many oscillograms in Mr. Newbury's paper convey to our minds an unusually clear picture of the phenomena from standstill to synchronism, of the transients produced by the varying reluctance of the magnetic circuit due to the projecting poles, and those caused by temporary changes when the connections are altered. Inasmuch as the physical conception of a phenomenon frequently is of more importance than the mathematical, especially to the engineer or student who does not design the apparatus, the graphical oscillograph records are of great value.

Mr. Newbury states: " These facts show the desirability of starting synchronous motors with the field circuit closed (and so eliminating the high voltage from the field winding and the switchboard), except in special cases where unusually high initial starting torque is required. For such applications a high resistance damper winding is necessary, the benefits of which in producing torque would be largely nullified by the closed field of circuit. In such special applications, however, care must be taken to insure that the insulation of the entire field circuit will withstand the resulting voltage." This statement applies to motors with rotors equipped with squirrel cage windings and laminated poles. Mr. Newbury has not commented at all on synchronous motors with solid poles. We wish to call attention to the very desirable effects which can be produced

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with solid pole rotors in which eddy currents are crowded into thin shells toward the surfaces, (the well known skin effect phenomenon), whereby the starting torque is increased, whereas the number of inter-linkages of flux with the field turns is reduced, with the result that the induced voltage in the field coils is lowered.

We give below some data from actual solid pole machines which were available for the tests. From them it will be seen that the induced voltage with solid poles is small as compared with that obtained with laminated poles in which the squirrel cage construction is embodied. Instances of these latter are cited in Mr. Newbury's paper. We have taken as a basis of comparison the induced voltage with a torque of 30 per cent of normal full load torque, this value being as large as is usually demanded of synchronous motors at starting.

| Rating | | | | | D-C. exciting voltage | Rotor voltage for 30% torque |
|---|---|---|---|---|---|---|
| 2000-kv-a. | 11000-volt | three-phase | 50-cycle | 600 rev. per min. | 125 | 1690 |
| 180-kv-a. | 2300-volt | three-phase | 60-cycle | 150 rev. per min. | 125 | 1790 |
| 350-h. p. | 2300-volt | three-phase | 60-cycle | 257 rev. per min. | 250 | 2610 |
| 50-kv-a. | 240-volt | three-phase | 60-cycle | 1200 rev. per min. | 125 | 1440 |
| 100-kv-a. | 240-volt | two-phase | 60-cycle | 257 rev. per min. | 125 | 1230 |
| 150-kv-a. | 275-volt | three-phase | 60-cycle | 900 rev. per min. | 125 | 427 |

We do not favor short circuiting of the field coils at starting, since, for a given starting torque, not only is the line current increased thereby, but there is a possibility of the rotor refusing to accelerate beyond half speed unless the field circuit is opened. As stated by Mr. Newbury, and also in my reply to the discussion of my paper on *Self-Starting Synchronous Motors**, the rheostat resistance is entirely inadequate in assisting toward the reduction of line current for a given torque at the instant of starting. Motors with solid rotors have been built successfully for a number of years, and so far as we are aware, all of them are started with the field circuit open, the induced voltage in no case being prohibitive, no disastrous results having come to our attention as a result of the induced voltage.

It is interesting to note that with the solid pole construction, the torque is not proportional to the second power of the voltage, as is generally assumed, but to a slightly higher power, about 2.1 to 2.5 Similarly, the other quantities vary in a different manner than generally assumed. For example, in a certain 100-kv-a. solid rotor synchronous motor, the following relations were found by plotting results on logarithmic cross section paper:

1. Torque varied as 2.5 power of voltage.
2. Torque varied as 1.73 power of current.
3. Current varied as 1.38 power of voltage.

*PROCEEDINGS A. I. E. E., April 1912; Discussion October 1912.

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4. Power input varied as 2.53 power of voltage.
5. Torque varied as 1.05 power of kilovolt-ampere input.
6. Kilowatt input varied as 1.05 power of kilovolt-ampere input.
7. Torque varied as the first power of kilowatt input to rotor.

A comparison of the above relations will reveal their consistency.

We believe that the departures indicated above from what would seem to be the most rational laws are due chiefly to the increased crowding of eddy currents into the shells of the rotor surfaces as the current is increased; thus the reactance of the eddy current paths is reduced, the current is proportionately increased, the power factor is slightly increased, etc. There are advantages in these relations, among them being that they result in a not inconsiderable gain in torque for a given increment of voltage, especially when the demand for such torque is greater than was first anticipated.

At first thought it may appear that the starting characteristics with the solid construction are predicted only with great difficulty due to the uncertainty of the laws which eddy currents follow. We would therefore call attention to the method given in my paper on this subject, and state at this time that we have been using this method for about three years with great success. We have recently modified the method so as to include exponents other than generally assumed, such as indicated above. With these modifications our method is substantially the same as previously described. In fact we believe that greater accuracy in the prediction of starting characteristics can be secured with the solid construction than with the laminated squirrel cage construction, there being less uncertainties in the former than in the latter.

The above is not intended to be more than a partial comparison of solid and laminated pole squirrel cage rotors.

It is now generally conceded, that insofar as the current taken when breaking loose from rest is concerned, the air gap should not be made smaller than would be best suited for the motor after it comes into synchronism and is excited in the ordinary manner. I wish to call attention, however, to my statement given in reply to the discussion of my paper previously referred to: "When operating at synchronous speed without direct current excitation the current drawn from the line depends almost wholly upon the magnetomotive force required to force the flux across the air gap." From this point of view it will be seen that the effect of the air gap upon line current may be of considerable importance.

In Fig. 7, Mr. Newbury shows that the current after synchronism is less than at any time during acceleration. This would imply that the air gap is small, since as stated above, the air gap reluctance plays the chief part in the current taken after the machine locks into synchronism with no direct-current

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excitation. In the various speed-torque curves shown in my paper, the current after locking into synchronism is somewhat greater than just before synchronism is reached. If a synchronous motor is designed to give double torque for pull out and is intended for unity power factor operation, the air gap will generally be of sufficient length to cause the current after locking into step to be greater than at about 95 per cent of synchronism. On the other hand, if the motor is designed with a small air gap and is intended to operate with leading power factor for balancing some of the lagging current in a system, the air gap may be so short that the current flowing when the motor is in synchronism without any direct current excitation is less than at any point during acceleration.

Mr. Newbury starts his synchronous motor on fractional voltage and excites the fields before throwing over to full voltage. He states: "The armature circuit is momentarily opened by throwing from the low voltage to the high voltage and current drops to zero during this interval." If the circuit is to be opened and then closed, his method might be a desirable one in cases where stored energy in the rotating parts is high, frictional torque comparatively small and the mechanical angle between adjacent poles comparatively large, such as would be the case, for example, with synchronous motor-generator sets. On the other hand, were the synchronous motor to drive a reciprocating air compressor, the motor operating at a small angular velocity, the frictional resistance being rather high, the mechanical angle between poles small and the stored energy small, the rotor may change its phase position appreciably during this transitional stage. When full voltage is then applied, there is a possibility of setting up rather high mechanical forces and of causing a momentary large current rush. Hence, we may conceive of trouble ensuing in cases of this kind. It may then be best to throw on full voltage before applying direct-current excitation. If the circuit is kept closed during the transition from fractional to full voltage, we believe it best in all cases to excite the fields on fractional voltage, so as to reduce to a minimum the current which would flow after full voltage is applied.

It is usually undesirable to apply as much as unity power factor exciting current in order to cause the motor to lock into synchronism provided synchronous speed cannot be obtained without the application of such current. In Figs. 11, 12 and 13 and accompanying description in my paper referred to above, it is shown that there is a critical value of excitation for each speed which will give maximum torque, beyond which the torque drops off, but the current in the stator increases. A knowledge of this characteristic may prove valuable to the operator who has had difficulty in causing his motor to lock into synchronism, or finds the current drawn excessive for his supply system.

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DISCUSSION ON "SUGGESTED SPECIFICATIONS FOR TESTING HIGH-VOLTAGE INSULATORS" (PEEK, SANDFORD AND THOMAS) COOPERSTOWN, NEW YORK, JUNE 25, 1913. (SEE PROCEEDINGS FOR JULY, 1913.)

*(Subject to final revision for the Transactions.)*

**F. W. Peek, Jr.:** The line insulator is an important factor in determining the success or failure of a transmission scheme. The requirements in present insulator specifications in no way provide for uniform porcelain. Destructive puncture tests are generally made on a few selected units which may indicate a very good insulator. On account of the great lack of uniformity in most porcelain these tests do not determine the performance of the bulk of the insulators which are manufactured later and put on the line. It is thus seen that uniformity of the porcelain is one of the most desirable features of a line insulator. I should like to bring out a few points that should be covered. In almost all other engineering work the strength of a given material is known and can be depended upon within a small per cent of the value indicated by test pieces. The material is uniform, and uniformity is a necessity. If structural steel varied a tenth as much as most porcelain used in present line insulators, there could be no "sky scrapers." Tests then, should be such as to secure uniform porcelain. This might be accomplished by requiring the destructive uniformity test, or the impulse test, made on insulators taken at random from different parts of the kiln at each firing. Again the specifications might require that a certain percentage of the insulators of each kiln at each firing pass the factory test otherwise *all the insulators of the kiln* at the given firing be condemned. For instance—if in one firing in a given kiln 50 per cent of the insulators fail to pass the factory test, and if in the next firing only 10 per cent fail to pass the factory test, the insulators in firing No. 2 would be much more reliable. A greater percentage would stand voltage rises on the line.

I do not believe that the factory tests made on all of the insulators should be too severe. For example, an exceedingly high voltage of steep wave front, or short duration, may be impressed upon an insulator without any apparent damage, but nevertheless the insulator is weakened. It may be that after nine of such applications there is no visible change but on the tenth application puncture may occur.

This is probably one reason why insulators that have long given good service after a time begin to break down, by the weakening due to accumulative effect of impulses received in service caused by arcing grounds, arcing over of poor insulators, lighting, etc.

It is desirable to make such tests, but only on insulators that are not to be used on the line. These tests indicate what can be expected of the bulk of the insulators if the porcelain is uniform.

Some suspension insulators recently came to my attention which had passed factory inspection. These would ordinarily have been placed in service. On breaking a few it was seen

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that the porcelain was very porous. Such insulators puncture at very low voltage when dry, and when the glaze becomes checked, breakdown will generally occur in practice. Moisture is undesirable in the cement even when the porcelain is good. Cases have come to my attention where, due to the cement and moisture, the metal pin was chemically affected. A coating formed on the pin. The pin, thus increased in size, placed the porcelain under great mechanical stress, probably producing tiny cracks. When puncture occurred in such insulators due to lighting, even when dynamic was not on the line, the cap was ruptured as in a boiler explosion, dropping the line to the ground. The explosion was probably caused by sudden expansion of moisture in the cement. The mechanical stress and tiny cracks therefrom weakened the insulator so that puncture also took place at line voltage. Moisture-proof cement seems desirable.

It is very important that when arc-over occurs, the design should be such that it takes place completely around the string and not from unit to unit in cascade. Complete arc-over is most likely to be obtained if the voltage balance of the string is good. When arc-over takes place in cascade the equivalent of successive impulse tests are played on the units as the arc approaches the tower unit, until finally, when the tower unit is reached, the full line voltage or over will be on this unit until it arcs over or punctures. A cascade arc also heats the units more than a complete arc, and breakage due to heat, and hence dropping of the line, is likely to occur.

It is not often realized that altitude makes a vast difference in arc-over voltage of insulators.

In making insulator tests, the transformer ratio should be calibrated with the sphere gap to include wave shape. Voltage may then be measured by ratio if the same method of voltage control is used.

In all engineering work the cost of various factors must be so divided that a maximum return is obtained from the investment. Engineers should realize that it is better to pay more at the start for a good and wisely selected insulator than to pay many times later by the loss of prestige due to poor service, and by damaged apparatus, to say nothing of the replacement of insulators. Each insulator that punctures or arcs over sends out impulses of high frequency which may weaken or destroy other insulators and apparatus.

While good uniform porcelain is necessary, it must be remembered that good porcelain does not always mean a good insulator, that good insulators may be weakened by improperly adding perfectly good porcelain.

My " Suggestions for Specifications " do not require an ideal insulator, but are requirements which I believe can be met at the present time by any manufacturer at reasonable cost. The suggestions are given not so much to make fixed specifications,

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but rather to bring out points not often realized. It is to be hoped that it will not be long before insulators are designed with due regard to the dielectric circuit, and that porcelain is either superseded or becomes a uniform dependable product.

**J. A. Sandford, Jr.:** In looking over these specifications with the criticisms, from the insulator manufacturers' standpoint, I would like to have you look at them as much as possible from the standpoint of specifications written to cover the requirements which are necessary in order to produce a good quality of insulator, and not so much a specification to cover the design of the insulator which the purchaser may choose. Undoubtedly, a set of specifications which the purchasing engineer writes must include paragraphs covering certain points that will govern the design, or performance tests, you might say, of the insulator completely made up.

It would seem to me as though, if it were possible to do so, it would be well if all specifications for tests that are required to demonstrate the performance of an insulator could be written up and isolated from the tests that are required to demonstrate the quality of the porcelain in the insulator to show that good insulators are being shipped. The reason I say that is this: After the insulator has been decided upon and the contract has been signed, the greatest thing that has to be contended with, very often, is the judgment of the man sent to the factory to select the individual units for insulators out of the lot put before him. For this reason it is advisable to have as few points as possible left to be decided by the inspector. If the purchaser's engineer decides all points concerning design, it will only be necessary for the inspector to see that good material is furnished; that it is according to drawing, and that the proper tests are applied to all units. It seems to me it would be more satisfactory and to the advantage of all concerned if these things could be separated, but that is hardly possible. At the same time, from the factory standpoint, that is the way the specification should be looked at; *i. e.*, simply from the standpoint of producing good insulators of the design already contracted for.

Referring to the paragraph headed " Corona " in Mr. Peek's specifications, I believe I am perfectly safe in saying that there is not a single type of suspension insulator on the market to-day that would not show corona around the metal stud cemented into the under side of the unit, if tested at 1.3 line voltage, assuming this to be 110,000 and the number of units per insulator as seven. I am pretty sure that there are a good many 110,000-volt insulators in use to-day that will show corona at about 65,000 volts. To be sure, it is very slight, but at the same time it is visible, and there again comes up the question of judgment of the man who has these things to decide as to how much he is going to allow. If you leave the wording in the specification so that it will read " there must be absolutely no sign of corona," prospective purchasers must buy a different

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insulator from that which has been used for like conditions in the past with seemingly satisfactory results.

Referring to the pin type of insulators, there is one thing which might have been added which would have read something like this: " In no case any porcelain part to be tested at less than 70,000 volts." As a matter of fact, we never test any porcelain part ourselves at less than the voltage that the part is designed to stand when assembled as a part of a complete insulator, and we think that is a safe practise.

Now referring further to the pin type specifications, mechanical test, that is stated as a definite figure at 2000 lb. I think that this value would apply alright in all cases for insulators of 25,000 volts or higher. I think possibly, however, that this value should have been left blank, because in the case of some of the smaller insulators, say 10,000 volts, or 11,000 volts, it might be found possible on some designs to approach that figure, but it is my experience in 90 per cent of the cases where we are called upon to apply a certain specification test to the pin type insulator as indicated, that the test usually resolves itself down into a test of the pin, because the pins generally bend at a considerably less load than 2000 lbs., and particularly on 60,000-volt insulator of the largest size.

Referring to the paragraph headed " Minimum Distance from Insulator to Grounded Objects," and " Number of Insulators to be Tested at one Time," and " Factor of Safety—Dry," etc.; when Mr. Thomas received the first draft of the specifications I submitted to him, he asked me several questions, and these paragraphs might be considered as answers to those questions. In other words, they are the view that the porcelain manufacturers take of these subjects, particularly from the point of producing good quality insulators, not that some of these points might and ought to be included in the performance test, preliminary to the placing of the contract.

Under the heading of: " Quality of Water for Rain Test Purposes," the first time I encountered this difficulty was when we were put to it to make a certain suspension type insulator come up to certain requirements under the rain test, and I could not do it with the equipment I had, using everything as it was installed. We had our water from artesian wells, water coming up through several layers of gas beds, coal fields, etc., so in order to take up the problem and solve it we took the identical insulator disks tested in our own factory, the spraying outfit and everything that was movable, and transported them to Pittsfield, Mass., and we made another test there. The results were rather startling. We then took the specific resistance of the water; the first (Lisbon) water was 880 ohms, and the second (Pittsfield) water was 7000 ohms. Later we installed in our factory for this kind of work a little half-inch steam trap and tank to collect water from our heater system, and letting the water cool down and using this water for similar testing

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purposes. The specific resistance of this water was 30,000 ohms. I have the apparatus so arranged that I can turn one valve for one water and another valve for the other water, and the difference will run as high as 40 per cent.

I think the specification that has been written by Mr. Thomas, with those points left blank, so far as the actual value is concerned is a good one, and as I stated here, in my report, this method of obtaining a good water may be put in practise. I think this apparatus could very likely be installed at any place where the test was likely to be made.

Referring to the dew test, from our standpoint it does not show anything in the performance of the insulator over what can be obtained in other ways. In the winter time I believe we can get a better test than any dew test would be by simply hanging the insulators out of doors and bringing them indoors and applying the test immediately. In this way you get a coating of moisture over the insulator which is better than that put on by steam or any other method.

The question of the capacity of the equipment is a thing which seems to be more or less a bone of contention. It is oftentimes specified, but often winds up, and probably has to wind up, by the engineer accepting what he finds at the manufacturer's plant at which it seems most advantageous to him to place his order. I think in nearly every case all the insulator manufacturers have a good equipment, and it seems to me that so far as any routine factory tests are concerned, that it need not be thought of in the specification. If there are any special performance tests where very careful note is to be taken of small variations in the performance of the insulator, then it is well to specify the various conditions, and among others the capacity of the equipment; but generally tests of that kind are made in a laboratory which has at its disposal various capacities of equipment and therefore such specifications may be admissible.

Now the method of controlling the voltage is subject to about the same limitations; that is, the potentiometer method, I believe, is good, but you realize the manufacturer is cutting down his costs just as far as he can for the factory tests and the potentiometer method of making the test will be very expensive. Take for instance a porcelain plant. Either one of our plants is probably as large as any other one plant in the business, and even at that we only require about an average of 80 h.p. to drive the whole factory. If you are going to load up a considerable per cent of that by using up power in water resistance, the people who are paying the bills will object, and I can see no reason why that should be necessary, except again in cases where performance tests are being made and a careful note has to be made of small differences, in which case it looks to me like a laboratory proposition and should be so treated.

You can see I am looking at this purely from the standpoint

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of the quality of the porcelain; therefore the grounding of one end or the middle of the test circuit goes along the same line except that for convenience it is very much easier for us to use the middle point grounded, on account of the fact that we have only to insulate through the buildings at half potential. We were compelled to put up sprinkler systems everywhere, and the less voltage we have to insulate in the factory the better off we are.

In regard to the paragraph concerning the breakdown of the insulator. Generally the breaking down of an insulator means the total destruction of that insulator, and if it would be consistent, I think it would be well to have that so understood.

The corona discharge, etc., is often specified, and with reference to what Mr. Peek says, that there shall be "absolutely no corona," if we make a performance test at our factory, or at some other factory, or at some neutral point, and along comes an inspector and we make another test, and in his judgment the above specification is not fulfilled, what is going to be the answer? It seems to me the items I have taken up in that last paragraph on page 1655 and the paragraph at the top of page 1656 should be wholly and finally decided before the contract is signed and then remain as decided, because you cannot change the insulator afterwards. I have seen strings of insulators sometimes among which, right along in the same string, there will be one unit absolutely dark between two units that show considerable corona.

As to the test for the puncture strength of the insulator, such test to be made under oil, I think this test is a very good thing. I cannot quite agree with Mr. Thomas, however, as to the method of raising the voltage by a thousand volts a minute, or whatever other time might be adopted, because ordinarily the factory equipment at an insulator factory is not calibrated, the low voltage meters which they have are not calibrated so that they read directly in kilovolts on the high-tension side. I rather like the method which I suggest here in the last part of this section. I used the old method myself at one time, but since then I have had a considerable amount of experience in applying the voltage in this way and I may say it works out very well indeed and will show up results as well as or better than any other method I ever tried for testing under oil.

As to the last paragraph, there is not anything better that I know of that can be said on that than to look at Mr. Nicholson's paper for this part of the discussion. First of all it is a design test, and it is difficult to apply because ordinarily the mechanical testing equipment in the factory may or may not be anywhere near the electrical equipment, and it means there must be provided special arrangements, etc., for rigging it up. But there are one or two things which Mr. Nicholson says here which, if they are substantiated by more tests later, it would seem to me would justify by good proof our taking the stand that I have indicated in this last paragraph, viz., in eliminating such a test,

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because you will see in Mr. Nicholson's discussion that he says: "In our effort to explain these results, mechanical loads were applied to insulator disks and then removed, voltage being applied after the removal of the loads. In other words, the electrical test followed the mechanical test. Almost identical results were obtained by this method as in the simultaneous electrical and mechanical tests. This fact seems to indicate that puncture occurs by reason of injury to the porcelain by the mechanical load, rather than by a combination of mechanical and electrical stresses acting simultaneously." If that proved true, in more extended experiments—we have not done much on it ourselves—I see no reason why then we should not apply a routine test to all units, which we do now. We may have to raise that a little and then apply our flash-over test with a definite time-limit rather than an instantaneous test, I think, and accomplish just as good results; in fact better, I believe, than by trying to determine the result from using the simultaneous test.

Further on Mr. Nicholson says, "Moreover, it is noteworthy that usually an insulator during or after a mechanical load which caused puncture would withstand flash-over voltage for several seconds' time before puncture occurred. These observations indicate that mechanical loads insufficient to actually crack the porcelain may overstrain it to a point where its dielectric strength is greatly reduced." I do not know, but I think that if all the insulators that were put to that test were of uniform vitrification, this difference would not exist; in other words, if the insulator was damaged at all, it was punctured practically instantaneously with the final voltage. It seems to me if that condition is going to exist, the thing I spoke of a short time ago should be introduced and I have written this down as an addition to that statement: "If this condition is found to prevail after more numerous data have shown such to be the case, the final electrical tests after the mechanical pull should be for a definite length of time, not for the so-called 'instantaneous' application."

I think if that condition exists, a test, perhaps one of two minutes, or whatever may be thought to be a proper time element would weed out any such cases.

What we would like to see would be a set of specifications drawn up that will not put any more fussy testing and experimental work than necessary up to the manufacturer after the contract is signed. It seems to me all these things should be determined beforehand and that afterwards all there is to be done is to be sure that each and every insulator and each and every piece of porcelain of a completed insulator, in the case of the pin type insulator, is perfect or as nearly perfect as we can make it. It makes it easier for the inspector, the manufacturer and the purchaser, and the purchaser will get just as good material in the end.

**P. H. Thomas:** I will take a few minutes to call attention to certain parts of the third specification, the one drawn up to

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embody what seemed to be the best and most practical features of the specifications which you have just heard discussed.

On page 1658, section 6, I have suggested a factor of safety for testing on metal parts. I do not believe such a requirement has been usually made, and I do not suppose it is necessary to put very much stress upon it, but it gives a criterion for the guidance of the man who is designing the mechanical parts.

On page 1659, paragraph 9, reference is made to the absorption of moisture by the porcelain. This is taken from Mr. Peek's specification, and is, I think, a very important feature. Personally I am inclined to believe that the amount of absorption is a very good measure of the density and quality of the porcelain. I would call the attention particularly of the manufacturers to the question as to whether they feel that this value given in paragraph 9 can be reasonably and reliably attained. Mr. Peek gives an absorption of not more than 0.25 per cent, and Mr. Sandford, in his case, gives 0.1 of 1 per cent, with a differently worded method of making the test. I have put in Mr. Sandford's figures in the specification, and ask that this point be discussed. One-tenth of 1 per cent may be too severe a requirement.

At the bottom of the page you will notice that I have made a careful distinction between routine tests and design tests. This is in line with the request of Mr. Sandford that when we have once decided on the design then it remains to make tests on individual units which shall insure that the insulators reasonably correspond to these designs. All that is required for the routine tests is that once in a while the method used for the routine test be calibrated by the prescribed method of making tests, and any reasonable method of checking up the voltage as shown on the test can be used. That gives the manufacturers an opportunity of using any apparatus which they may have available, provided it is reasonably good, for handling their factory output.

Paragraph 16, with relation to frequency, is a compromise. Ideally, we should test every insulator on the frequency at which it is to be operated, but it is a hardship on the manufacturers to require testing at the various commercial frequencies. I am inclined to think that in ordinary cases a 60-cycle test would show pretty nearly the same results as 100-cycle or 125-cycle test, up to 40,000 volts, provided the other conditions were as specified. The variations between frequencies in testing are due to many other things than differences in frequency, such as differences in the characteristics of transformers, the characteristics of the generators and the methods of the application of a voltage.

The next paragraph "what constitutes a breakdown," is perhaps the first definite injection of such matter into a specification. This paragraph comes from Mr. Sandford's specification.

The oil tests, it seems to me, are absolutely necessary in important lines. How large a percentage over the flash-over voltage shall be required for the test under oil for the puncture

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test is open to debate. It is given as 125 per cent in this specification.

As to paragraph 22, in reference to mechanical tests on pin insulators. I would like to read the last sentence. This is a novel statement, whether it will be approved or not I do not know. It is as follows: " In case of failure the question as to whether the insulator or the pin is at fault shall be determined by testing again with a solid steel pin turned from a piece of round steel of such dimensions that this piece of steel acting as a pin for the insulator will not bend under the above-mentioned load." In my opinion it is not sufficient to put in a perfectly good pin to find whether the insulator will stand the overload, but the pin which is used should be one which will not bend or spring in service, so it seems to me worth while to make the test on the design with the pin you are going to use.

Paragraph 25, and other paragraphs in this group, refer to routine testing. The question is as to how long these tests shall be continued, and that is one of very considerable practical importance. When you are making a test of one thousand insulators, it makes a difference whether every one must be tested one minute or five minutes.

I would call on Mr. Nicholson to read the contribution which he has made, which contribution has been printed, and which describes some of his tests on a simultaneous application of electrical and mechanical stresses. I consider this a very important matter, and I would like to have it called to your attention at this particular point in the consideration of these specifications.

**L. C. Nicholson:** A series of tests, not yet completed, has been undertaken to determine the performance of suspension type insulators when subjected simultaneously to electrical and mechanical stress.

We find that mechanical loads do not affect the flash-over value of the insulators, but do not affect the puncture or dielectric strength. A load much less than that necessary to cause apparent mechanical failure induces puncture at dry flash-over voltage. Thus, insulators having an ultimate mechanical value of 9000 to 12,000 lb. (4080 to 5440 kg.) will puncture when subjected to from 4000 to 9000 lb. (1815 to 4080 kg.) pull and dry flash-over voltage simultaneously.

Mechanical load was applied by means of an overhead hand crane, three insulator discs in series being anchored to floor. Voltage was obtained from a 50-kw., 25-cycle, 250,000 volt testing transformer, regulation being effected by a water rheostat.

Expressed in per cent of the number of discs tested under ascending mechanical loads we find that:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5 | per | cent | puncture | at | | | 4000 | lb. | (1815 kg.) pull. |
| 8 | " | " | " | " | or | below | 5000 | lb. | (2270 kg.)pull. |
| 22 | " | " | " | " | " | " | 6000 | lb. | (2720 kg.)pull. |
| 50 | " | " | " | " | " | " | 7000 | lb. | (3175 kg.) " |
| 90 | " | " | " | " | " | " | 8000 | lb. | (3630 kg.) " |
| 100 | " | " | " | " | " | " | 9000 | lb. | (4080 kg.) " |

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Several types of insulators from several different manufacturers were experimented with. No marked difference between the different kinds was found to exist, with perhaps one exception. This was a "strain type" insulator with extra heavy metal parts. Only a few of these were available, but none of those tested punctured at a load of less than 8000 lb. (3630 kg.), and some of them withstood 10,000 lb. (4540 kg.) successfully. The ultimate strength of this insulator was from 10,000 to 12,000 lb. (4540 to 5440 kg.)

In our effort to explain these results, mechanical loads were applied to insulator disks and then removed, voltage being applied after the removal of the loads. In other words the electrical test followed the mechanical test. Almost identical results were obtained by this method as in the simultaneous electrical and mechanical tests. This fact seems to indicate that puncture occurs by reason of injury to the porcelain by the mechanical load, rather than by a combination of mechanical and electrical stresses acting simultaneously.

Usually, though not always, puncture occurred previous to any audible noise from the insulator, such as would indicate crushing or cracking of the porcelain. Moreover, it is noteworthy that usually an insulator during or after a mechanical load which caused puncture would withstand flash-over voltage for several seconds' time before puncture occurred. These observations indicate that mechanical loads insufficient to actually crack the porcelain may overstrain it to a point where its dielectric strength is greatly reduced.

We believe the shape of metal parts, as well as the size, shape and distribution of grooves in the porcelain, are important factors in this matter. Undoubtedly other factors and effects are present and the subject is one deserving careful study and investigation.

As to the theory of what happens I am not able to say. I have simply pointed out in my discussion the results which are obtained.

There is not much audible noise. In many cases the insulator will hold the voltage for 30 seconds before it punctures, indicating that the material may have been strained, although not actually cracked. This factor varies with different shapes of hardware and different shapes of porcelain, depth of grooves, distribution of grooves and all that sort of thing. I have not begun to find out the nature or extent of the phenomenon.

**P. H. Thomas:** You can see this work of Mr. Nicholson was a serious matter. There are in service a great many strain insulators of the type tested, and much difficulty is experienced with them in the respect indicated. Our specifications ought to protect us against it. At the present time we do not have data enough to conclude just the significance of this feature which Mr. Nicholson points out. It may be that further experiments will show that the weakening of the dielectric by mechanical stress is an extremely common occurrence.

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We are especially interested in what the cause of the trouble is and what is the nature of the action. It is a speculation at the present time, but the thought must occur to us that there is a mechanical deformation of the parts which are under a strain approximating the elastic limit. We have metal parts, porcelain parts, and cement parts, and under the strain there must be a certain amount of mechanical change of shape. Porcelain is a brittle substance and it is possible there are tension strains developed in it which will cause not a clear crack, but an opening up of the material which allows a little penetration of charge. This speculation is supported by one of the comments of Mr. Nicholson that there was one set of disks which did not act as badly as the others and that this set had excessively heavy mechanical parts. If it is true that distortion is the cause of the difficulty, it can be corrected.

I think we have done all we can in these specifications to fore stall the effect of mechanical stress in calling for the making of the electrical routine test after the mechanical test. Mr. Nicholson's study as far as it goes, shows the test is no more severe made at the time of the mechanical test than it is afterwards.

I hope that all engineers interested will make full criticism of these proposed specifications.

**H. W. Crozier:** What has become of the idea that each unit in a string of insulators should be able to stand the line potential? That idea was advanced some time ago, that is, that each unit should be able to stand, as a puncture test, the line voltage.

I want to add a word of caution in regard to the mechanical tests proposed. Mr. Nicholson's discussion particularly brings this out. In a good deal of work which we did, samples of the insulators were tested to destruction. In our practical insulator work we are not testing samples, but we are testing actual insulators, and we must take care we do not do things to the insulator in our testing which will reduce their efficiency. We may take strain insulators capable of standing 15,000 lb., and we can easily realize from Mr. Nicholson's discussion that if we overload these insulators we greatly reduce their resistance to electrical puncture. If we take all the insulators of a line and apply a severe mechanical test to them, we have reduced the resistance to puncture of the whole number of insulators by a margin of forty or fifty per cent. We will have to test a lot of insulators mechanically to provide for strain insulators, but for the other insulators, which are going to act as supporting insulators and throughout their life may not be called upon to support more than a few hundred pounds, it would be desirable to omit the mechanical test altogether.

**P. H. Thomas:** Has Mr. Peek, or Mr. Sandford, anything to say about making each unit in the string stand the line potential? That would seem obviously impracticable when you have high voltages. It might be practicable in some cases, but if you have seven or eight insulators in a string, it would be impracticable, in my opinion.

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**J. A. Sandford, Jr.:** If Mr. Crozier adds under oil, there is no insulator made today that will not stand the line potential under oil.

**H. Koganei:** With regard to the oil test of insulators, I made a series of tests and observed some phenomena which are not yet well explained. The insulators tested were all of pin type for working voltages, 15,000, 25,000 and 35,000 volts. At first I made the arc-over test with three times working voltages for five minutes. Then selecting ten insulators from each size which arced over without puncturing, I immersed them in oil to make the puncture tests. The puncture voltages varied from 80 to 90 per cent of the arc-over voltages.

It seems quite reasonable to show lower puncture voltage in oil due to the concentration of the dielectric field near the terminals. To eliminate this effect of the field distribution, I selected another lot of ten insulators from each size and pasted tin foil on the top and the pin hole. Even in this case they were all punctured at the same voltages near the centre of the electrodes and none at the edges.

The voltage was measured by the needle gap which checked very well with the voltage calculated from the turn ratio. The voltage was increased at the rate of 1000 volts per minute.

The flux distribution in the latter case, near the puncturing point, may be considered to be more uniform than in the arc-over test. Nevertheless, the insulators were punctured in the oil at least 10 to 20 per cent lower voltage than they will puncture in the air. Unfortunately, these tests were made just before I started from Japan and I did not have enough time to get any further result. The insulators were made in Japan.

**F. W. Peek, Jr.:** The suspension insulator as a rule does not act in that way under oil. The only explanation would be some local concentration of flux due to the oil, and with the suspension type, the breakdown under oil always takes place between pin and cap where the oil can in no appreciable way affect the flux distribution. The flux distribution would be affected in the pin type insulator. I do not think the oil has any peculiar effect.

**M. T. Crawford:** Mr. Sandford recommends the wet flash-over voltage test for pin type insulators to be not less than 175 per cent of the operating voltage. My experience has been that not less than 200 per cent normal voltage is a better minimum, or possibly 225 per cent as recommended by Mr. Peek. I have also found it to advantage to have each insulator marked with an identifying stamp by the inspector, so that none are skipped in the test by mistake during a rush delivery. On one job of over 30,000 insulators tested in this way to over 200 per cent normal voltage. There have been practically no failures in four years' service, whereas another job with a less rigid test has given a considerable number of failures, although they have identically the same design and are used under the

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same operating conditions. In this case the greater cost of the insulators tested with the higher pressure was more than warranted.

**P. H. Thomas:** In regard to the propriety of omitting the mechanical test on insulators which are not to be used as strain insulators, something may be said both ways. In the third specification, paragraph 22, page 1662, a blank is left for the value of the pull test. If it is desired, insulators can be made in two classes, one to receive a test commensurate with the ordinary strain of the line insulator, and the other for the high strain of the strain insulators; since by the breaking of a conductor a high mechanical strain is likely to be brought on a suspension insulator, it seems to me it would be, as a matter of fact, and of practical wisdom, dangerous to try to use a suspension insulator that would not stand the strain of a broken conductor.

**J. A. Sandford, Jr.:** It seems to me the strain insulator is the one to stand the load. If there is any damage done by applying the mechanical stress, that is the one to receive the stress, and it should not be received by the span insulators.

**L. C. Nicholson:** Insulators intended for service should not be damaged by mechanical or other tests, but it is evidently unwise to place an insulator in service subject to a certain mechanical load which has not been actually tested somewhat in excess of the loading it will receive under actual operating conditions. If there is any question as to the ability of the insulator to carry this load, two or more insulator strings should be used in parallel.

There has been considerable trouble with strain insulators on transmission lines. This has been attributed by some to too high mechanical loading, and by others to the self-induction or choke coil effect of the conductor loop as usually employed at angle or dead-end towers. No one seems to have any definite explanation of what is responsible for strain insulator trouble. The mechanical-electrical tests cited show that dead-end insulators may be weakened electrically by mechanical loading. Furthermore, these tests were of short duration, and do not tell us what effect would come from alternate loading and unloading over long periods of time such as occur in practice.

In addition to mechanical loads, internal stresses of considerable magnitude are induced by atmospheric temperature changes. In a paper by Mr. Austin before the National Electric Light Association, at Chicago, it was shown that a stress of at least 400 lb. per sq. in. may be induced. Since this value is practically one-half the ultimate strength of the porcelain, it appears that medium mechanical loading in combination with temperature effects may in time result disastrously to the insulator.

These considerations indicate that the shape of suspension insulators may be changed to advantage—better to withstand loads and temperature changes. Are we not making an error

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in the construction of the insulator in confining a small knob of porcelain in a perfectly rigid iron pocket?. Or, would not some substance other than cement, which would be more elastic, be better in this respect?

In general, the points mentioned in the specifications under discussion are good, but I believe they do not go far enough. There are a number of important things about insulators which we do not know, and which we appear perfectly content to leave to the manufacturers, without making an effort to find out about them. The manufacturers are in general reliable and honest, but have not so far sufficiently distinguished the technique of insulator design from the commercial production of insulators. Electrical engineers are willing to leave these matters entirely in the hands of the manufacturer, and depend upon final test and inspection to secure satisfactory insulators. For example, we never ask any questions nor make any requirements relating to the composition of insulators we intend to use. We leave the entire ceramics of the matter absolutely in others' hands, and have made no efforts to study intelligently the composition or firing of the porcelain. In a matter so important to the electrical industry, I feel that the American Institute of Electrical Engineers or some other body should undertake to become familiar with insulator production, to the extent that specifications may be prepared covering not only the testing, but the composition and production of insulators.

The point raised by Mr. Peek concerning proper spacing of units to prevent flash-over in cascade, is in my experience of slight practical importance. With the usual spacing of units, when dry the string flashes over, but when wet the units flash-over individually. Since the wet condition is the practical one, I fail to see any advantage to be derived from a close application of the theory based on dry flash-over.

**C. O. Mailloux:** I would like to say a few words about going into the mixing room too early. I have had some experience in cases where it was necessary for the consulting engineer to decide whether there was to be or was not to be a mixing room. I have found it to be true in electrical engineering, and in all other professions, that the shoemaker should stick to his last. I think it is dangerous for the electrical engineer who has not made a thorough study of ceramics, at least as thorough as the ceramic expert himself, to go into the mixing room and tell the ceramic manufacturer what to do. There is a parallel case in the manufacture of insulation for wires. I have found that in undertaking to tell the manufacturer of insulation for wire, how to manufacture and how to apply the insulation, one was liable to hamper the operation most seriously and make difficulties which not only tended to, and actually did, increase the cost of the output, but also decreased its insulating and lasting qualities. Hence, in my opinion, it is quite as well to

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let the ceramic expert confine himself to that specialty. I do not care how strongly we insist on the *results*, but when it comes to the methods of accomplishing these results, I think we should leave to the manufacturer the widest possible latitude.

**Paul M. Lincoln:** Concerning the quality of water which is recommended for making the rain test, I have run across a good many different kinds of water, and I find there is a tremendous variation so far as their electrical resistance goes. Some water is a fairly good conductor and some is a pretty good insulator. It seems to me Mr. Sandford is quite logical in suggesting in his specifications that the water which is used for rain tests in testing insulators shall be condensed steam, for the reason that the water which wets the insulator in practise is of the same nature, viz: rain-water, and it is practically pure. The only opportunity it has for gathering up impurities is in the course of its descent through the air, and while it may take up a very small percentage of impurity from the air I do not believe that is sufficient to make its character very different from that of the condensed steam which Mr. Sandford suggests.

Another point is one in which I cannot agree with Mr. Sandford. He suggests that the connection of the transformer which shall be used for testing whether it be grounded in the middle or at one end—shall be at the manufacturer's convenience. I know from my own experience that there is a tremendous difference between these two methods of connection. It is on account of the disposition of the static field around the insulators.

Insulators, when used, have the pins grounded, and I believe the test should be made under the same conditions, as nearly as possible, and I therefore believe the specification for testing insulators should carry with it the condition that the pin of the insulator shall be grounded during the test.

**Percy H. Thomas:** We meet both conditions in some specifications. The design test is made on the nearest approximation test to the service conditions, and for the routine factory output the test conforms to the calibration of the low voltage voltmeter, with the result that we approximate the actual conditions, and make the output test with the easier apparatus.

**A Member:** I would add a little to what Mr. Mailloux said about the danger of going into the mixing room, and I will refer to some experiences I was familiar with, in which one body of engineers, in making a report, stated that they had told the manufacturer not only what to put in the mixture for the insulation, but how to put the insulation on the wire also.

In any consideration of the subject of the composition of mixtures of any kind, and their application, we must realize that improvements are being made all the time and that any specific directions which an electrical engineer might give on this subject would not hold for very long.

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**Hugh T. Wreaks:** Referring to the point brought out by Mr. Sanford about the question of packing, this seems to me very important. In specifications of many other kinds of material, specific attention is given to how the material should be packed. We have had occasion to note damage in shipment of insulators, and even in cases where the penalty for breakage came on the manufacturer, a good many were damaged in shipment.

Judging from experiments of Mr. Nicholson, it seems to me not unlikely that many insulators may be strained in shipment with consequent weakness developing in the field, the fault in this case being due, not to how insulators were manufactured, but how they were packed and handled in shipment.

**E. E. F. Creighton:** The endeavor to standardize the tests on insulators is, I think, a valuable move in the right direction. Even if the rules are not adopted, they will have their value. Although it is impossible to get any information at the present time on the proper manufacture of porcelain and therefore it cannot be included in these rules, yet this is one of the most important features regarding the insulators. Sooner or later some one must make a careful investigation for the information of electrical engineers of the following factors:

*First.* The effects of each of the ingredients that go into porcelain.

*Second.* The proper deposition and drying of this material without allowing flaws to be formed in the body of the material.

*Third.* The proper temperature and proper length of time of firing for proper vitrification.

There is little practical use in stating that porcelain should be properly vitrified unless some specific directions can be given. The absorption of water by porcelain has been used as a rough test of the degree of vitrification but the method is unsatisfactory in several respects, especially in the fact that it requires the destruction of an insulator. From the experiments I have made I think it is possible to develop some other method which will be not only more satisfactory but will leave the insulator intact after testing.

Along a different line of endeavor some experiments made on clays relating to vitrification, are apropos to the problems of porcelain manufacture.

Our tests were made on the vitrification of clays, using as a basis of vitrification the stability of the material as a resistance; at 1200 degrees there was very little vitrification; at 1300 degrees vitrification was fairly started; and at 1350 degrees complete vitrification took place, although as high a temperature as 1500 degrees was used at times to advantage, for the particular work in hand.

Another test made in vitrification was relative to the time of heating. The material was heated successively for periods of about one-half hour and measurements were taken after each heating. The curve showing the general relations is given in the accompany-

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ing Fig. 1. The degree of vitrification is represented by the conductivity. In the curve the reciprocal of conductivity, namely resistance, is given. These curves of time versus vitrification vary in form according to the temperature used. Naturally, the higher the temperature, the more rapid the vitrification.

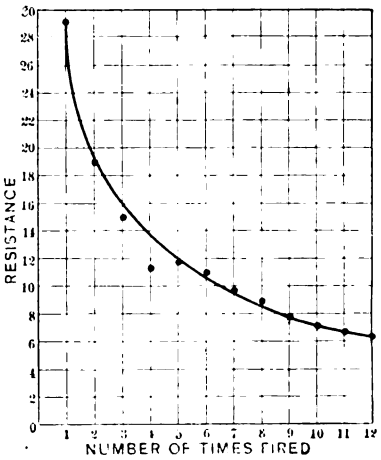


FIG. 1

This curve shows the relative degree of vitrification of clay by the decrease in ohmic resistance. The duration of each firing was approximately one-half hour. The last few tests showed almost constant resistance, which we presume indicates the final condition of vitrification for the particular temperature used, namely, about 1400 deg. cent.

Although these tests were not made directly on porcelain for insulating purposes, it seems that they would show the necessity of scientific work being done in the manufacture of porcelain. Until this work is done results will vary tremendously.

In all other forms of insulation the manufacturer aims never to test the insulation to anywhere near its complete dielectric strength. Destructive tests are made on samples of material, and the methods of manufacture are regulated to keep the product uniform. With the methods of manufacture fixed, a factor of safety is taken on the dielectric strength of this material and is then not strained above the danger zone. Finally, it would seem that this would be the proper way to take care of the manufacture of porcelain insulators. If the proper chemicals are chosen in the first place and the material is properly worked and properly fired, it will be necessary only to test it in such a way as to get rid of evident flaws. In the past there has been turned out a considerable quantity of imperfectly vitrified porcelain, and this is liable to be damaged by the tests which are made to discover the flaws.

In testing for flaws, it has been found that the high-frequency currents from an oscillating transformer produce a general stress over the whole surface of the insulator, each successive spark traveling over new surface of the porcelain skirts. Still further, we have found that by limiting the potential of the oscillating transformer, the strain on the porcelain can apparently be made even less than on the 60-cycle test. This is due to the fact that the higher frequency favors the production of creeping sparks along the surface. With the same applied potential the creeping spark will extend farther as the frequency increases. At the same time, the dielectric losses in the porcelain will increase as the frequency increases. Herein are the relations

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which should be carefully studied. There is an evident probability that a high-frequency test can be made which will not strain good porcelain but which will tend to develop and pick out accidental flaws in the material.

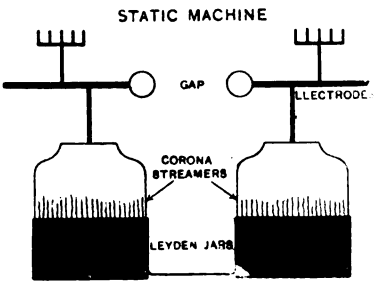


FIG. 2

In the foregoing criticisms it is evident that we have started from the point where the electrical engineering leaves off, namely the point of design; it has been stated many times that an insulator should be so designed that it will spark around the skirts rather than puncture the porcelain.

I want to emphasize a point brought out by Mr. Thomas in his remarks relative to the frequency at which the insulator is to be used. Actually, when you consider the use of the insulator, it is never over-strained at 60 cycles or 25 cycles. It is strained by lightning frequencies and by the frequencies that occur through accidental arcing grounds, and it is for that reason I think that all testing should be done with high frequency. The failures of insulators, outside of the effects of mechanical strains, can be attributed entirely to lightning and arcing grounds.

Some potential tests made a few years ago with panes of glass in air and in oil seem to answer the question of Mr. Koganei. If an ordinary piece of window glass in the air with the electrodes on the outside of it, is subjected to potential stresses, it is possible to raise the potential to a higher point than if it is immersed in oil. We made a series of tests to determine the reason for this and came to the conclusion that it was not due to the distribution of potential around the electrodes, but was due to the safety-valve effect of the corona streamers that run along the surface of the glass in air but not when it is immersed in oil.

Consider the ordinary conditions in a disruptive curcuit as shown in Fig. 2. The potential is built up by direct current until the gap is bridged and then the oscillation takes place in this circuit. At the instant of disruptive discharge there will be seen on the surface of the glass jars a tremendous number of little streamers which emanate from the metal covering. These little streamers are the relief valves that protect the glass from puncturing.

If the jars are immersed in oil and filled with oil, the corona streamers are almost entirely suppressed and a puncture of the glass will take place for a smaller gap setting than when the glass is surrounded by air. The corona irself forms extra surface adding to the electrostatic capacity of the jars. Any sudden local surge thus relieves itself by creating a larger capacity and thus lessening the potential that would otherwise occur accord-

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ing to the fundamental law $E = \frac{Q}{C}$. When the corona is suppressed there is no relief valve and consequently a local surge will hammer harder on particular spots in the glass; the extra strain will cause a puncture.

The indications of the existence of local electrical surges over the surfaces of condensers are not lacking. One might as well expect a bucket of water thrown into a trough to produce no splashing as to expect the electric stresses under disruptive discharge to gently and smoothly distribute themselves immediately in the condenser. As an experimental proof of the existence of local surges the following facts are given. When only one leyden jar on each side is used as shown in Fig. 2, a much larger gap can be made to spark without puncturing the glass than if many are used on each side. It was determined that this effect was not due to weakness of several of the many jars used.

**Ralph D. Mershon:** I have a number of points here, of which I have made note, upon which it was my intention to speak, but in view of the lateness of the hour I will only take up one or two of the principal points. It seems to me that the question that has been raised before should be emphasized a little more, that is as to the object of such specifications as these. These are specifications under which insulators are to be purchased from the manufacturer, under which he is to supply them. Then it seems to me, as pointed out by Mr. Sandford, that all the questions of designs, form of insulation, flash-over, and that sort of thing should be determined before the contract is let, and then forgotten. That is a matter which we cannot usually specify, it seems to me. Our object in preparing any specification, and recommending one, if we are to recommend one, is not to enable engineering work to be automatically done, but these specifications are prepared and are to be used as a guide in procuring any given product determined on.

The preliminary determination as to design and the characteristics that will be given presumably to all the units is one that should depend upon the judgment of the engineer. If it were possible to determine all the characteristics, then it would not be necessary to have any tests at all, perhaps, or any specifications except some rough ones of a general nature, but it is not possible to determine in advance all the characteristics. You cannot lay down a hard and fast rule for the puncturing of the insulators, for instance, in the matter of test under oil, so that it is necessary to draw up specifications which will bring about the production of an article along commercial lines and in very reasonable approximation to the kind of product we are after.

Closely connected with that is the proposition made by Mr Nicholson in regard to going into the ceramics of the matter. My advice in that connection would be general. I have made a little study of the side of this subject which relates to ceramics,

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and my experience so far has been that the more deeply you study it the less you know. You will find that the art of ceramics today is hardly on an engineering basis. It is approaching that, and we have ceramic engineers, but the ceramic engineers meet serious obstacles every once in a while, as I know. There is a suggestion I might make in place of the one which has been made, and that is that we get in touch with our friends, the ceramic engineers, and arrange for some joint meetings on this matter, so that we may both learn something. On our side we will learn something as to the uncertainty of the manufacturer of electrical porcelain. I think it is more uncertain than any other material that enters into electrical construction, and our knowledge of it is limited, both in regard to the electrical properties and the mechanical properties. Our knowledge of the mechanical properties is a very indefinite one at the present time. We have but very little information on the tensile strength of porcelain, and such as we have is very conflicting. It depends very greatly not only upon the composition of the porcelain but upon its mechanical treatment during manufacture. For instance, I presume a good many of you would assume that the tensile strength of porcelain, or ceramic material, because some of it is not worthy of the name of porcelain, increased with the vitrification. Now, that is not necessarily the case at all. Some of the strongest objects, that is, strongest with relation to tensile strength, made of ceramic material that I ever tested, have been the most porous and the ones most easily broken by a little knock. I remember one sample of porcelain which was tested up to 2200 lb. per sq.in., which is very high, and someone knocked this piece of porcelain on the floor and it broke into three pieces.

There are a lot of problems which are yet to be solved in regard to ceramic material, both from the chemical, electrical and mechanical side, and it is a pretty complex problem. I think Mr. Mailloux's remarks in that respect were well to the point.

To my mind one of the most important tests is the puncture test under oil, but when you come to apply it and use it as a criterion as to the quality of product, it is extremely difficult to determine how it shall be applied. Mr. Sandford has mentioned the percentage of the product which shall be tested under oil. All right, but suppose you test it under oil and it falls considerably below what you expect it would do, and what the tests of the first samples had encouraged you to believe you would get. What are you going to do about it? Say you have a large order of insulators to be got out on time, and the manufacturer doing the best he can, and his material is considerably below the puncture test you thought you were going to get. It is extremely puzzling to know what to do. You cannot test all of your insulators, that would be almost prohibitive as a matter of course, and few manufacturers have the facilities so that you could test them all under oil. In one case in my own experience we did this—we assumed we could not ask the insulator manufacturer

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to do any better than it was possible for him to do. The most we could ask then was that we should get as good porcelain as anyone else got. The particular insulators in question had a lower flash-over value than some others being turned out, so that if they were tested in air they would be tested at a lower voltage as regards puncture than the other insulators being turned out. We could not tell then, from a test in air, as to whether the porcelain in these insulators was as good as that in the others. When we came to make the test under oil, if the puncture values were lower than we thought they ought to be, we agreed that we should have the right to test some of the other product that was going through the factory and which was passing the routine test through air, under oil, and if ours tested out as good as they did, then we were subject to negotiations, even though it was not as good as we thought. If it was not as good as that, we were in the position under the contract to exert some considerable influence. That was agreed upon.

It may be possible to work out some better arrangement, but it is exceedingly puzzling to know how to control your product, when you can only test a small part of it, and when you are dealing with a product which is notoriously non-uniform. On this matter of uniformity I agree with Mr. Peek. I would rather have insulators which run very uniformly in a lot tested than even those in which the puncture value was considerably lower than might be obtained with some other product which was less uniform.

There is one thing Mr. Peek mentioned which I would like to discuss further, and perhaps get some further information on the point, and that is the objection to using the sphere gap in making the insulator tests. He suggests it would be better to calibrate the transformer. I think in many cases it would be, but my reason would be that of convenience. His reason was not quite clear, that was, in making the end test on the insulator the voltage on the spark gap might be higher than otherwise. It seems to me the insulator gets the same voltage as the spark gap does, if the apparatus is properly collected up and located, and I cannot see, from that standpoint, the objection to using the sphere gap.

It seems to me it is important to have the wet and dry tests as nearly the same as possible, so that the idea of specifying the flash-over test dry shall be at least equal to a certain amount seems to me is a little bit irregular. I should say that the most logical way to specify it would be with reference to the wet flash-over test. It seems to me the precipitation in some specifications is pretty high. One inch depth in five minutes would occur to me to be amply high enough for most, if not all, places in the United States. That is considerably higher than the maximum precipitation ever recorded by the U.S. weather bureau. If you want to add a factor of safety, do not add it through the precipitation test. I think it is better to add it through the

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voltage to be impressed on the insulator. Also in regard to the matter of precipitation, I hope there will be some further discussion on Mr. Thomas's suggestion of inclining the insulator and using a vertical spray instead of a spray at an angle. It is difficult to get a spray at an angle which will be uniform and accurately directed. It would be much easier to accomplish the same conditions with a vertical spray and the insulator at an angle. The objection may be made that that does not simulate the conditions of practise. In reply to that you can say that we do not know much about what the conditions of practise actually are, and there is considerable question as to whether the 45 deg. spray simulates them any better than any other method of procedure would. In any case, what is the difference provided we have certain values which we know approach the practical value of the insulator? Is it not much better to have a condition of test which we can repeat with some assurance of accuracy even though it does not simulate completely the conditions of practise.

There is nothing said on the cement—how the insulator shall be handled after it is cemented. In the first place, it should not be used soon after cementing, and should be kept above the freezing point. I know of some pieces of work in which the insulators were allowed to freeze before they set and when they got out on the line there was some trouble. That was a case where it was not possible to test the insulators as a completed whole, and they had to be tested in separate parts. Where you test them, after assembling, that point is not of such great importance, except that it is always important not to have your deliveries held up by the failure of a lot of insulators, and, of course, that is important from the manufacturer's standpoint, not to lose a lot of the product.

I should also like very much to hear from the insulator manufacturers as to the absorption tests which have been proposed, whether or not they are satisfactory to them, whether they are too difficult, or whether they are likely to result in a product whose existence is not justified.

I would also say that I agree with Mr. Nicholson in his remarks in regard to the flash-over values of the insulators. It seems to me that a desirable insulator is one which will flash-over the unit always before it will puncture. If that is the case, why not space your units far enough apart so that approximately, at least, you get the benefit of the full value of each unit. If there is a power arc-over, as a rule it will go to the outside plenty quick enough, so that none of the insulators will be broken by the stroke of the power arc, if they are not to be broken by the stroke of the power arc at all. In other words, I doubt if you will find any difference in the breaking of the insulators whether the power arc starts around the insulators or between them. If the amount of power is enough to break the end unit, it may go along a line of insulators, a string of units, if the arc persists long enough. Whether it

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flashes clear around the string, or starts clear around individual units, there is little difference in practise, so far as we have been able to observe.

**Percy H. Thomas:** President Mershon was the one who suggested having the spray vertical and the insulator at 45 deg. Of what effect, in one of these specifications, would be the provision that we separate the design test from the routine test, as you suggest? What would you have done with the specification?

**Ralph D. Mershon:** I would have improved or changed the matter.

**Percy H. Thomas:** Would you have left out half of it?

**Ralph D. Mershon:** I would place the most stress upon those things which will control the product as we go through the process of manufacture. I do not think I would put the matter of design in the form of a specification at all. I do not see why we should supply specifications for the design of the in ulator at all. It is likely to impair progress, I think, and in any case the engineer in charge of the work ought to have enough knowledge and exper ence to exercise his own judgment in regard to questions of design. The usual course is to get samples from the different manufacturers and test them. If there are any new designs which have been brought out, you can compare them with regard to corona and in regard to string ratio, and all of the other points that are involved in the design of the insulator itself and in regard to the puncture value of the insulator. After you have done that, you want a specification to which you can fairly require conformity, and it will result in bringing forth as uniform a product as the state of the art will permit.

**Percy H. Thomas:** Is not that exactly what we have in the first specification? We have the routine test separated from the design test in a perfectly plain manner. The first part may not be called a specification, but have these things stated, and call attention to the necessity of uniformity in the product and leave the greatest freedom for variations in design. We do not limit the development of the art, but want to call attention to the way tests should be made, and things of that sort. I agree with you in the matter.

**Ralph D. Mershon:** The remarks I would add in regard to that would be directed more toward the supplying of specifications for design at all. Any specifications we agree upon should be directed toward bringing the product through and not to the matter of the design of the product.

**E. M. Hewlett:** I think that the last point Mr. Mershon brought out is one of the most important. The general design of the system should be settled before any decision is made as to the particular insulator which should be used. The proper insulator to use will be determined by the voltage of the line. An insulator designed for a 70,000-volt line would naturally show corona at a lower point than an insulator designed for a 100,000-volt line. Also, insulators designed for any given voltage at a

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given altitude will show corona at a lower voltage at higher altitudes. Thus at points where a line crosses a mountain range it might be necessary to use insulators of a different design than those used at lower points so that all the insulators will show corona at about the same voltage.

In reference to the arc-over test, we find that many manufacturers consider a puncture or a flash-over test with a testing transformer equivalent to an actual line test, but Mr. Mershon has shown the fallacy of this. He brought out the point that whereas you might flash over and strike between the insulators and probably break the whole string, the power arc-over, that is, the arc-over on a power system as distinguished from a flash-over on a testing transformer, often improperly called a power arc, would probably throw clear of the insulators in an instant. If the insulators fail it may be because a wind is blowing at the time, whereas a similar flash-over clear, without adverse wind, might not have created any trouble. The flash over the entire string of insulators might have been blown into the string of insulators if it had been drawn in by a flash in between.

In reference to the rain test, the 45-deg. angle test, the amount of water, etc., I find that many times tests are run with an abnormally large amount of water, a great deal more than actual precipitation conditions justify, the insulators being first tested under actual precipitation conditions and then, if they do not arc over, the amount of water is increased until the insulators do arc over. It would seem a much better test to duplicate actual precipitation conditions, increasing the voltage until a flash over results, because this method gives a better idea of the behavior of the insulators under actual conditions. It should be obvious to everyone that when excess water is used the information being sought from the test is not and cannot be obtained, which is the maximum possible arc-over voltage at maximum rain conditions and not at five times this point.

Now considering the rain test at an angle of 45 deg. If rain is falling at 45 deg. there is considerable wind, and if the wind condition is not duplicated in the test, the water will stream over one disk to another and the insulators will flash over at much less voltage than they would under actual weather conditions because of the wind blowing the streams of water so that they will not drip from one disk to the next one below it.

Then there is another point. We have seen tests where the insulators were damaged because they were too far apart, whereas the individual test on each disk was good. Because the insulators were placed a little far apart, they flashed around the individual disks, whereas if they had been placed closer together the flash would have been around the whole string. Also insulators are often arranged simply to meet the ideas of the engineers testing them, making the test a personal rather than a physical equation.

In reference to the absorption, while 0.01 of one per cent

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in porcelain is possible, I doubt whether this absorption can be maintained at this time in the case of large orders, because there is a difference in the temperature in different parts of the kiln, as well as in the different burnings, etc. If you demand 0.01 of one per cent absorption, I think it probable that the cost will be increased.

On the basis of cost, I think also that the tests suggested are too long, and that too many insulators are tested. The purchaser will have to pay the additional cost, it has to go somewhere, and if the insulators are subjected to severe tests and long tests, which entail some hardship on the manufacturer, the extra expense must naturally be put into the price of the product.

The altitude is not considered in the specifications, and I do not suppose that it should be, but a reference should be made so that it will be remembered by engineers selecting insulators for higher altitudes. In this connection, if only a small portion of the line runs at a higher altitude it would be a hardship to make a specification for this altitude include all the insulators which are used at the lower altitude.

**P. H. Thomas:** I think you are right about that.

**E. M. Hewlett:** Regarding the appearance of the corona at different altitudes—an insulator of a given design and with a certain size pin will show corona at a definite altitude which given climatic conditions, and some reference should be made to this so it will be considered in selecting insulators for various altitudes. There should be a practical specification drawn up for the inspector's use, so that he can determine whether the insulators received are made of the proper material and are of the dimensions called for, etc., and that they will pass certain electrical tests. I also believe that specifications should not specify the details of manufacture, because no good would be accomplished. It is always to the interest of the manufacturer to work out efficient methods of design and manufacture to accomplish the various purposes desired and he is often not in a position to manufacture, without added expense, according to other methods which might be specified. If you limit the man in the porcelain factory in the making of porcelain or seek to influence the way in which he handles his materials, you are going to handicap him seriously, because some clay combinations are more suitable for thick bodies and some for thin bodies, and the characteristics of the clay must be considered in working out a design for a given purpose.

In reference to the porcelain, I have been working out different designs of porcelain for the last fifteen or eighteen years, and I agree with anything that anyone says about the varying character of the product. We make insulators of various kinds, as it is necessary to do so in order to obtain the different forms which are required. It is often difficult, if not impossible for us to obtain just what we need from outside manufacturers.

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From experience I have found that the ceramic engineers and foremen in charge of the porcelain factories often unintentionally mislead us as to the form in which it is possible to make given insulators. There are many factors to be considered in manufacturing porcelain that do not occur in other lines, and it takes a great deal of experience with the design and manufacture of porcelain and its uses for one to be reasonably able to predict what results will be obtained from various designs.

As to the advisability in making up the strings of units which will not flash over before the line potential is reached, this may be feasible for some voltages, but it is obvious that after a certain voltage is passed it will not be practicable. For instance, it would be difficult at the present time to make up a string of insulators for a 140,000-volt transmission line in which each unit in the string could be tested to flash over at line voltage, 140,000 volts. Such a design would be practically prohibitive.

The specifications given for suspension insulators often call for strength far in excess of the strength of the conductor and the possible strains on the system, and consequently introduce a factor which may call for a design of insulator electrically inferior, though testing mechanically stronger than is necessary, whereas if the specifications did not call for these excessive strengths, better electrical characteristics could often be secured. It should be kept in mind that the initial strain which an insulator will stand does not necessarily prove that it will maintain this great strength over a long period. Some insulators that have stood great strains at first have been known to drop the conductor in a comparatively short time after having been put in service and having been subjected to only a small portion of the original testing strain, due to the methods of fastening the links together.

As to the mechanical test, I think the points made by Mr. Sandford and Mr. Nicholson about this are correct. I think they should be made as general tests, though, and only a comparatively small number would be necessary to test in that way. You ought to test your design in that way, the same as you would for other designs, and then run at a proper safety factor and use enough strain insulating sections in multiple to get the desired strength. Then as to the suspension insulator. A suspension insulator is not ordinarily called upon to stand so much strain as a strain insulator, even under emergency conditions, as the suspension insulator is nearly always put on the lighter tower, and if subjected to the same strain as the strain insulator the tower would probably be pulled over.

**H. W. Crozier:** I want to say a word in regard to the matter of vitrification. There are two kinds of tests, one a general test as to the material you are going to get and another a detailed test of each particular piece of porcelain. There is nothing said whatever in the specification about the vitrification test of each particular piece of porcelain. When I first learned something about the porcelain business, Mr. Sandford was working on the

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same problems. We would set up a long row of insulators for test and very quickly the inspector learned to pick out pieces of porcelain which were not thoroughly vitrified. Many pieces, however, were doubtful and it was found that soaking in a tub of water over night had a very great influence on the insulators. A large proportion selected by the inspector as doubtful would fail after the soaking test, showing insufficient vitrification.

As has been said here, the manufacture of insulators is not by any means uniform, and from any one kiln you can take insulators which are very fine and right alongside of them you will find insulators which are not vitrified. After a little experience, the suspected ones are picked out and set aside, and sent back to the oven and refired, and by that means the manufacturer saves the loss which would be caused by their failure. I would like to see something put in the specification to cover this question of test for the vitrification of individual pieces. I think the best way to do that is to take the porcelain and soak it in water—that would be the test which I should apply. Whether we should require this 0.01 per cent of absorption, I do not know, but soaking in water will soon determine. We can get a porcelain insulator which will stand the electrical test, but we want to be certain that the insulator will not deteriorate in service. In the same lot of insulators that I have spoken about we did have a large number of insulators deteriorate in service. That was due to the fact that the insulators were not thoroughly vitrified. They were made in a new factory and no one had sufficient experience to properly select the insulators which were not thoroughly vitrified. If these insulators had been soaked, I believe not many would have passed the test. After the line had been in service about two years, one section of the line where the first four carloads were used was found to give a great deal of trouble due to failure of insulators.

As to the other question raised about the strain insulators, in regard to the mechanical test, words have been put into my mouth which I did not use. I anticipated we would use two different types of insulators. If we are going to apply additional tests to a lot of insulators, we will naturally raise the price, so it would be better to have one lot of insulators for the strain insulators and another lot of insulators for the span insulators. If the span insulators are accidentally seriously loaded, and break in the line, that is a very serious matter, but one which should be carefully considered in the design. As a rule, for heavy loads it is better to use two or three strings of insulators in parallel for strain insulators.

**P. W. Sothman:** The problem before us is one that cannot be disposed of by following ordinary thumb rules. To me, every insulator represents an integral part of a system, requiring a special study for each individual installation. For it is obviously impossible to select an insulator for a certain service and then assume that this same insulator will withstand any

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other service under any other conditions, on the strength of the fact that the voltage of the line is the same.

I believe it would not be wise to draw up specifications for the manufacture of insulators by setting cast-iron rules for the manufacture and testing. What is most needed in these specifications are well defined principal requirements. And, further, I believe the manufacturer and the engineer should arrive at a mutual understanding as to how the best results can be obtained. I think one of the most advantageous things from a practical point of view which we can undertake to do is to urge the manufacturer to improve the character of the porcelain, in order to obtain a more uniform product.

Mr. Peek has advanced several points which can only be viewed from a purely academic standpoint, and Mr. Sandford has given us his views from the manufacturer's standpoint. Mr. Sanford does not wish the engineer to settle all questions, but wants to give us what he thinks best and not necessarily what we need. I think we should specify clearly what we need. But do not let us step in and tell him how to do it. It is his business to know that.

With reference to the tests of the insulators, it appears that tests on dry and wet insulators vary considerably. I do not believe that any of our practical engineers have ever seen an insulator fail under a wet test, and in spite of this they still specify wet tests. It was pointed out, and I think it was endorsed by Mr. Sanford, that the water used for these water tests has a range of 100 per cent in conductivity. Mr. Mershon remarked that some water was a good insulator and other water a good conductor, and I have always found that to be the case. I have seen wet tests on insulators that did not leave anything to be desired; however, when the insulators was tested in another room, it failed entirely under apparently the same test.

I absolutely agree with the remarks of Mr. Lincoln, who recommends the use of water from condensed steam. I agree with him that we should approximate as much as possible the natural conditions in specifying our tests. There is nothing gained by overstressing the insulator to such a point that it will fail soon after it is placed on the line. We want a commercial piece of apparatus, and for this reason we will have to be less academic and more practical in calling for something which will satisfy the operator. Now, to obtain these conditions, if the gentlemen who are in charge of the practical operation of a transmission line will join hands and heads with the insulator manufacturer, and study the subject thoroughly, we would be sure to obtain better results, and for that reason I would suggest that a resolution be passed turning over the work of the gentlemen who have presented these specifications to a committee to be appointed to work out the details in coöperation with the manufacturers, in order to avoid the danger of framing a specification that would do more harm than good. It should always

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be borne in mind that a chain is only as strong as its weakest link. The breaking down of insulators does not necessarily imply that the insulators, themselves, are at fault. In a good many cases, the trouble has its seat elsewhere. Distribution of stresses along the string of insulators and at their extreme ends, the design of cable clamps, its protection, etc., etc., all must be duly considered. Until all troubles and their causes are clearly understood and their relative value appreciated, both qualitatively and quantitatively, nothing can be gained by blindly adding material to an insulator with the object of making it safer against these causes.

**C. F. Scott:** The problem seems to be a triple one: first to determine, by research, what it is possible to secure in the way of satisfactory insulators; second, to determine, by research, what characteristics an insulator should have in order to be wholly satisfactory; and third, a commercial test to determine whether particular insulators meet these requirements, and conditions. The three elements are—research, engineering and commercial testing.

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# SPECIFICATION AND ANALYTICAL PROCEDURE FOR 30 PER CENT HEVEA RUBBER INSULATING COMPOUND[1]

REPORT OF THE JOINT RUBBER INSULATION COMMITTEE APPOINTED BY A GROUP OF MANUFACTURERS AND USERS OF RUBBER COMPOUNDS, 1911-1914

## PREFACE TO REPORT

### I. Specifications for Rubber Insulation

A DEMAND for specifications which will enable purchasers of rubber insulation to secure good material on the basis of competitive bids has existed for many years.

In recent years, there has been no difficulty in securing insulation having the dielectric strength, specific resistance, elasticity and mechanical strength required in practice. Indeed, with the possible exception of dielectric strength, these qualities are usually in excess of actual service requirements. There is another quality, namely permanence, which although equally essential, has not been so easy to obtain.

While the physical properties of rubber insulation are susceptible of positive determination by tests which can be made before acceptance by the purchaser, the permanence of insulation can be ascertained only in practice, often at great loss, inconvenience and even danger. It, should, therefore, be the aim of specifications to overcome this difficulty and by some indirect means, ensure that the manufacturers supply compounds having the required endurance.

This obviously presents a difficult problem, as it requires that some relation be established between permanence and one or more of the properties which are susceptible of test. It has been established by experience that *Hevea* rubber or the rubber of the *Hevea Brasiliensis* tree, when properly cured, is a superior grade which is entirely satisfactory for electrical insulation. *Hevea* rubber may, therefore, be specified with advantage, although certain other rubbers of good quality may be excluded. The rubber has, however, to be further identified as *Hevea* rubber of good quality, the materials associated with it in the compound must be known to be non-deleterious and the compound itself must be well prepared, applied and vulcanized.

Two types of specifications have been devised to compass these restrictions. The first type of specification proceeds on the assumption that certain physical characteristics are developed to an unusual degree by the use of *Hevea* rubber, especially the grade known as fine *Para*. Among the qualities affected by the grade of rubber, and alleged to be useful indications of the presence of *Para* rubber, are the tensile strength,

1. This report has been referred to the Standards Committee of the A. I. E. E. for consideration, and is printed in the Proceedings at the request of that Committee.



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elasticity and specific resistance. Accordingly some specifications have been issued in which one or more of these qualities is specified in an exaggerated degree. Experience has shown that such specifications are ineffective, as the specified physical quality can be obtained either by manipulation of poor compounds or at the expense of permanence in compounds made originally of good materials. In consequence of this, specifications based exclusively on physical tests have fallen into disrepute, but such tests now serve in modified form as adjuncts to other types of specifications.

The second type of specification to be considered is that in which a more or less rigid formula for the compound is specified and compliance with it exacted either by inspection during manufacture, or by chemical analysis supplemented by other tests of the finished product. Inspection which will really ensure compliance with such specifications is usually impracticable. Reliance must, therefore, be placed principally upon chemical analysis. Three difficulties at once arise. In the first place chemical analysis cannot *directly* ascertain the quality or quantity of the rubber which has been used in the manufacture of a compound; it can only determine these by the *indirect* method of measuring certain of its characteristic constituents. It is, therefore, necessary to present in the specification, a relation between the desired formula and the chemical findings.

The second difficulty is that in the past, chemists have employed diverse methods of analysis which give inconsistent results. It is, therefore, necessary to establish a satisfactory and standard procedure for analysis. The method of analysis must not only yield the information desired, but it must also be practical and capable of yielding uniform results when applied to the same compound by different chemists. In order to secure this uniformity, it is important to describe the methods of analysis in detail.

The third difficulty has been the non-uniform interpretation of analytical results.

The specification hereinafter presented is of the second or chemical type, in which an endeavor has been made to meet the three objections hitherto urged against such specifications. It contains a table showing the range of analytical results that should be obtained from a good compound containing 30 per cent of high class *Hevea* rubber, and is supplemented by a detailed analytical procedure. The specification is not complete as given, it being necessary to add appropriate electrical and mechanical test requirements.

The specification presented in this report should always be used in conjunction with the analytical procedure. The latter will, however, serve for the analysis of any compounds of the 30 per cent *Para* type with mineral fillers, provided the interpretation is made to correspond.

## II. Standardization of Specifications

The necessity of purchasing insulated wire under conditions of competitive bidding led the various departments of the government, the railroads and other large consumers, to issue specifications for rubber insulation. These specifications were based upon the individual experience or theories of a number of engineers, aided by suggestions from

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some of the manufacturers. For several years no attempt was made to standardize these specifications, and much trouble was given to the manufacturers by the diversity of requirements contained in them. In 1906, the Rubber Covered Wire Engineers' Association, consisting of representatives of the leading manufacturers, prepared a specification which was offered as a standard. This was followed in 1911 by the revised specifications of the National Board of Fire Underwriters, which, however, call for a comparatively low grade of compound. The former specification, although the best that could be agreed upon at that date, was so defective as to afford little or no protection to consumers. The latter occupies a field by itself, and make no pretension to specifying the highest quality of compound. Consumers desiring compounds of great permanence, therefore, continued to use their own specifications, altering them from time to time, in accordance with the best information available, with a growing tendency to rely upon chemical rather than physical tests. Some difficulty was experienced in enforcing these specifications owing to the inability of chemists to make concordant analyses of rubber compounds. This matter reached an acute stage in 1911, when Mr. E. B. Katte, Chief Engineer of Electric Traction of the N.Y.C. & H.R.R.R. Co., invited a number of manufacturers and consumers to a conference in order to discuss the possibility of standardizing specifications and analytical methods for rubber insulation. This conference was held at New York on the seventh of December, 1911, Col. Samuel Reber of the U.S. Signal Corps presiding.

After a full discussion of the subject, a committee was appointed to devise a specification and an analytical procedure for rubber insulation, the committee to report at a future conference.

This committee, which was originally known as the Railroads Rubber Committee and later as the Joint Rubber Insulation Committee, worked at the problem assigned to it for two years and presented a report to a second conference which was held at New York on October 15th, 1913, Col. S. Reber again presiding. The report was unanimously accepted by the Conference and the Committee authorized to continue in existence for another year for the purpose of making any revisions that might appear necessary in its report, as the result of a year of experience with it.

The membership of the general conferences at which the committee was appointed and to which its report was submitted, consists of representatives of the following interests:

U. S. Signal Corps,
U. S. Bureau of Standards,
American Chemical Society,
Lederle Laboratories,
New York Central Lines,
Pennsylvania R. R.
General Electric Co.
Hazard Manufacturing Co.,
Simplex Wire & Cable Co.,
Standard Underground Cable Co.

The organizations represented in the committee have been unstinting in devoting their unrivalled resources to this work, which could not have been carried out by private enterprise.

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While the acceptance of the report does not bind any of these interests to the official adoption of the specification and analytical procedure, most of the members were of the opinion that they would be adopted in due course.

The Association of Railway Electrical Engineers has adopted the specification in its standard wire specifications, and the Power Distribution Committee of the American Electric Railway Association has recommended its adoption by the latter association.

It is hoped by the Committee that other societies and users of rubber insulation will follow this lead and help to abolish the existing multiplicity of specifications and methods of analysis.

The Committee wishes to emphasize the preliminary character of the report and urges everyone interested in the subject to send to the Secretary any suggestions or criticisms which may be of value, so that such statements may receive consideration before the publication of the report in its final form.

The Committee also desires to express its thanks to the many gentlemen not members of this committee, who have participated in the work, especially to Messrs. D. A. Cutler, F. Dannerth, F. S. Deemer, F. A. Hull, M. M. Kahn, G. H. Savage and D. Whipple.

## III. Rubber

Those who are not familiar with the nature and sources of rubber may find some difficulty in understanding the report. The following brief outline of these subjects is therefore given, containing the best information that could be gathered.

Rubber is derived from certain tropical trees, creepers and shrubs found chiefly in South and Central America, Africa, and Southern Asia. When certain species of these plants are tapped, a thick milky-looking fluid or latex exudes from them. This latex is composed of very minute oil-like colorless refractive globules. Besides these globules, called caoutchouc or rubber-gum proper, which have a chemical composition represented by the formula $(C_{10}H_{16})_n$, the serum contains resins, protein and other compounds. Rubber is the coagulated latex, consisting of rubber-gum admixed with these impurities.

Rubber is furnished in America principally by the *Hevea*, *Micandra*, *Manihot*, *Castilloa* and *Hancornia* plants, usually in the wild state.

In Africa the principal plants are the *Landolphia*, *Clitandra* and *Kickxia*, also wild.

In Asia, there are the *Ficus* in the wild state and the *Hevea* in the state of cultivation.

In the Amazon valley, there are numerous species of *Heveas*, of which the most important is the *Hevea Brasiliensis*. This tree furnishes the most highly esteemed quality of rubber.

The *Heveas* in the Brazilian forests are cylindrical trees of an ashy color, from 20 to 30 meters high, and attaining a diameter of from 0.80 to 1.20 meters.

The usual process of tapping these trees is as follows: Incisions are made at about 3 to 3½ meters from the ground, by means of a long-handled

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hatchet. The object of this operation is to make the latex ascend from the roots, in an effort to repair the incisions. The milk that oozes out is mixed with bark and other impurities and is utilized to make an inferior grade of rubber known as sernamby. Two days afterwards, incisions are made 2 meters from the ground and tapping cups fastened at the lower part of them. The latex collected in these cups is said to be collected "prime" and furnishes the best rubber. On the following day, the process is repeated by making incisions about 7 cm. below the first, this being continued on successive days until the ground is reached.

The rubber is coagulated from the latex by smoking. This is accomplished by putting the latex on a spatula or flat stick, and holding it over a fire made from wood or Urucuri nuts, the smoke of which is rich in acetic acid and creosote or similar oily substances. The latex is thus dried in successive layers until a ball or biscuit weighing from 20 to 60 kg. is obtained. The smoke acts as a coagulant, evaporates the water and at the same time kills bacteria, which would cause decomposition. Rubber prepared in this way is known as "fine *Para*", but when the curds or semi-solidified latex deposited in the latex basin are incorporated with it, the quality is lowered and the product is known as "entrefine" or "medium fine". If these natural curds are collected separately, they are known as "coarse Para" or "sernamby", a name which, as mentioned above, is also applied to rubber coagulated on the bark of the tree. *Up-river Para* rubber is *fine Para* collected from the *Hevea Brasiliensis* trees in the headwaters of the Amazon and its tributaries.

The wild *Hevea* rubber of Brazil is shipped in biscuits which contain from 15 to 20 per cent of impurities, which can be removed by rolling and washing with water preparatory to use in manufacture. These impurities are absent from plantation rubbers, a circumstance which must be considered when the prices of wild and plantation rubber are compared.

Several kinds of rubber trees are raised on plantations, but the most important kind is the *Hevea Brasiliensis*. Just as the rubber of this tree in the wild state varies slightly in composition according to its habitat on the upper or lower reaches of the Amazon river, so in the cultivated state, a similar variation exists, but to a greater degree. The principal source of plantation rubber is Southern Asia.

The latex of plantation rubber is collected in much the same way as in the case of wild rubber, but coagulation is usually effected by the addition of chemicals. As such coagulation does not usually have the preservative effects of smoking, the better grades of plantation rubber are "cured" by exposure to antiseptic smoke.

The principal forms in which plantation rubber is prepared, are crepe and sheet, either of which may or may not be smoked.

In the preparation of crepe, the strained latex is poured into pails and a small quantity of acetic acid is added. This curdles the latex, the curds rising in the serum. The resultant curd is passed between steel rollers under a stream of water. From this process, the rubber emerges in long, thin, corrugated strips, having the appearance of crepe. The process is completed by drying.

For preparing sheet or biscuit, the latex is set in shallow pans, the acid added and the clot allowed to stand until it sets quite firm. The water

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is then squeezed out and drying completed in hot rooms. The curds which do not rise with the main clot are made into an inferior grade of rubber.

Curing is effected by hanging the rubber in an atmosphere impregnated with creosoted smoke, thus antiseptizing the rubber. It should be observed that coagulation with acetic acid and curing with creosote chemically simulates the Brazilian process of smoking with the *Urucuri* nut.

Both wild and plantation rubber are used in the manufacture of insulating compound. It is claimed that some difficulty is experienced in obtaining a high tensile strength with some plantation rubbers, and their lasting qualities have not been established as well as those of wild Brazilian rubber. It is, therefore, desirable, where the greatest durability is to be insured, that the grade of rubber should be *fine Para* or a plantation rubber of good grade which is practically indistinguishable from it by chemical tests, when compounded.

Most high grade rubber compounds for insulating wire are prepared by mixing rubber gum with sulphur and mineral or organic fillers, such as paraffine wax, ozokerite, ceresine, zinc oxide, talc, whiting, litharge, barium sulphate, and basic lead sulphate.

These ingredients are thoroughly mixed on heavy steel rolls, after which the plastic compound is either pressed on to the wire through dies or applied in the form of a longitudinal strip which is pressed into tubular form around the wire.

The covered wire is then placed in a chamber or vulcanizer containing either steam under pressure, or heated air. The duration of this heat treatment varies from less than one hour to several hours, depending upon operating conditions and the temperature, which is usually from 120 to 150 deg. cent. Under these conditions the sulphur combines with the rubber to form vulcanized rubber. This process of compounding and vulcanizing changes the character of the rubber so that its strength, insulating qualities and durability are enhanced.

W. A. Del Mar,
P. Poetschke,
E. L. Willson.
*Sub-committee on publication of report.*

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## PRELIMINARY REPORT OF COMMITTEE

Part I —General Report.
" II —Analytical Procedure.
" III—Explanation of Procedure.
" IV —Specification.
" V —Explanation of Specification.

### PART I—GENERAL REPORT

1. At the Conference of December 7th, 1911, it was resolved that a Committee be appointed to develop a means of specifying and analyzing rubber insulation, the Committee to report its findings at a future conference.

2. The Chairman of the Conference, assisted by other members, appointed the following to serve upon this Committee:

Mr. C. R. Boggs, Simplex Wire & Cable Co.,
Mr. W. S. Clark, General Electric Company,
Mr. W. A. Del Mar, N.Y.C. & H.R.R.R.Co.,
Mr. W. B. Geiser, " " " "
Mr. J. P. Millwood, Consulting Chemist,
Mr. P. Poetschke, Lederle Laboratories,
Mr. H. B. Rodman, Pennsylvania R. R. Co.

Later, at the request of the Committee and by unanimous consent of the members of the original Conference, the following were added:

Mr. J. B. Tuttle, U.S. Bureau of Standards,
Mr. E. L. Willson, Hazard Manufacturing Company.

The Committee thus constituted is composed of three railroad men, three independent chemists, and three representatives of the manufacturers. Of the nine members, seven are chemists and two are engineers.

3. The Committee immediately upon its formation decided to confine itself to the development of a specification and an analytical procedure for compounds of the 30 per cent *Para* type. In accordance with this policy it considered the available analytical procedures and developed several which formed the basis of further study. Samples of different rubber compounds were analyzed by these tentative methods. The results were unsatisfactory and the discrepancies were investigated. Sub-committees were formed to do much of this work. Twelve regular committee meetings, besides numerous sub-committee meetings, were held; thirteen different compounds were distributed to be analyzed by the entire committee, and many more compounds were experimented upon by the sub-committees and individual members.

4. The outcome of this work has been a gradual elimination of errors and the development of a procedure which, with experience, will give uniform and consistent results.

5. The Committee feels that the procedure which it has developed is not perfect and believes that it should be put into use for a year before being offered as final. With this in view the Committee hereby presents to the Conference, a preliminary procedure and requests the permission of the Conference to publish it and obtain the results of experience with it during the ensuing year. The Committee proposes to avail itself of the experience gained in this year and to incorporate whatever improvements it may decide upon in a final report.

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6. The Committee has also made a study of specifications for rubber insulating compound. It presents herewith a chemical specification for a compound containing 30 per cent of *Hevea* rubber with mineral fillers and requests that this specification, like the analytical procedure, be considered as tentative.

7. There may still exist the possibility of making compounds which will conform to the specification when analyzed by the procedure, but which are not compounded as desired. The Committee believes, however, that the probability of such compounds being supplied is very small indeed. After more experience with the procedure it may be possible to narrow the limits prescribed in the specification.

## PART II— PROCEDURE FOR THE ANALYSIS OF RUBBER COMPOUND

### *Object of the Analysis*

1. The object of this procedure of analysis is to determine whether rubber compounds comply chemically with the accompanying specification which is intended to secure compounds containing 30 per cent of the best *Hevea* rubber, and mineral fillers.

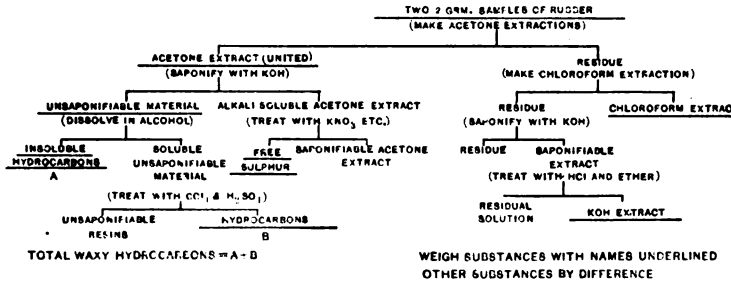


DIAGRAM A.—OUTLINE OF METHOD OF RUBBER ANALYSIS EXCLUSIVE OF FILLERS AND SULPHUR DETERMINATIONS

### *Outline of Procedure*

2. The general procedure is shown by the accompanying diagram A, which gives an outline of the separations to be affected by acetone and chloroform extractions, and saponification with alcoholic potash.

### *General*

3. Make the analysis upon the insulation after vulcanization and, whenever possible, before the saturation of the braid. Wipe the insulation thoroughly with a damp cloth to remove any adhering material, but do not remove waxy hydrocarbons from the surface.

4. If, however, a saturated braided sample must be used, remove the braid and sandpaper the insulation to a depth of at least 5/1000 of an inch and wipe with a damp cloth. In such cases report the condition of the sample.

5. Perform all determinations in duplicate and take the average value arbitrarily as the true value. Duplicate determinations must check within the limits specified.

6. Make blanks on all determinations and deduct the results accordingly.

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*Sample*

7. Remove the insulation entirely from sufficient wire to give a sample weighing about 25 grams. Cut this into small strips and grind slowly in either a No. O Enterprise coffee mill or a mill such as shown by the

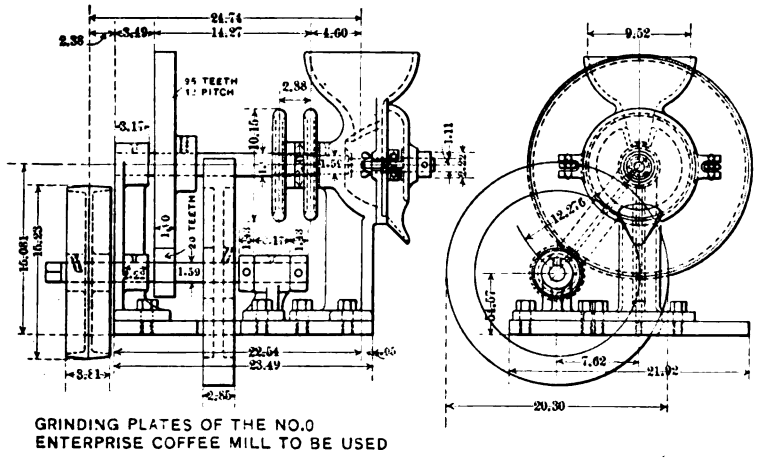


DIAGRAM B.—RUBBER GRINDER
(All dimensions in centimeters)

accompanying diagram B. Adjust the grinder so that not more than 20 per cent will pass through a 40-mesh sieve. Sift all the material through a 20-mesh sieve, regrinding what is retained on the sieve until the entire sample has passed through. The wires of the sieves shall be evenly spaced in both directions and shall be of 0.016 and 0.010 inches diameter in the 20 and 40 mesh sieves respectively. Remove with a strong magnet any metal that may have come from the grinder and thoroughly mix the sample.

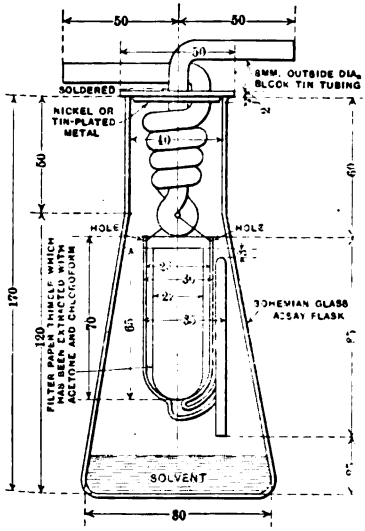


DIAGRAM C.—RUBBER ANALYSIS EXTRACTION APPARATUS
(All dimensions in millimeters)

*Extraction Apparatus*

8. The extraction apparatus shall conform with the accompanying diagram C. It shall be heated so that the period of filling an empty syphon cup with acetone and completely emptying it, will be between 2½ and 3½ minutes.

*Preparation of Reagents*

9. Acetone shall be freshly distilled over anhydrous $K_2CO_3$ using the fraction 56-57 deg. cent.

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10. Alcoholic KOH solution shall be of normal strength and shall be made freshly by dissolving the proper amount of KOH (purified by alcohol), in 95 per cent alcohol which has previously been distilled over KOH. The solution shall be allowed to stand for 24 hours and only the clear liquid used.

11. Ether shall be washed with three successive portions of distilled water and distilled, using the fraction 34-36 deg. cent.

12. Chloroform shall be pure and freshly distilled.

13. Carbon tetrachloride shall be pure and freshly distilled.

14. Reagents not otherwise specified shall be c.p.

*Acetone Extraction*

15. Extract continuously with 60 cu.cm. acetone for eight hours, two 2-g. samples that have been prepared within 24 hours. Unite the extracts in a weighed flask, using hot chloroform to rinse the flasks. Distill off the reagents and dry the flask and contents for four hours at 95-100 deg.cent. Desiccate until cool and weigh. Continue to dry for two-hour periods until constant weight is obtained. In drying, place the flask on its side but at a sufficient angle from the horizontal so that the extract does not appreciably run down the side of the flask.

*Unsaponifiable Material*

16. Add to the acetone extract 50 cu. cm. alcoholic KOH solution, boil under a reflux condenser for two hours, and evaporte to dryness, removing all alcohol. Add 10 cu.cm. water and 20 cu.cm. ether; heat until the wax etc. are in solution, cool, transfer to a separatory funnel, wash out the flask with warm water and then cool, finally with two 20 cu.cm portions of ether. The water volume should be 100 cu.cm. and the ether at least 40 cu.cm. Shake vigorously for two minutes, and allow the solutions to separate thoroughly. Draw off the aqueous solution into a second funnel, leaving in the first funnel the etherial solution and any flocculent material that may be present. Again rinse the flask with 20 cu.cm. ether and add it to the aqueous solution; shake vigorously for two minutes, and when separated draw off the aqueous solution and unite in the first funnel the etherial solutions and any flocculent material. Repeat, shaking with 20 cu.cm. portions of ether until the extraction is complete, using at least 120 cu.cm. ether. Wash the flask and the funnel, from which the etherial solution has been taken, with water, until they are free from alkali, subsequently using this wash water to wash the etherial solution. Continue washing with water until it has been washed twice after it shows no alkaline reaction. Retain with the etherial solution any flocculent material. Filter the etherial solution from the flocculent material, through a small pellet of extracted cotton, into a weighed flask, washing first with ether and subsequently with hot chloroform, using this to rinse the original flask and both separatory funnels. Evaporate the solvents and dry the extract to constant weight at 95-100 deg.cent; desiccate until cool and weigh.

*Hydrocarbons A*

17. Add 50 cu.cm. absolute alcohol to the unsaponifiable material and warm until solution is as complete as possible. Cool the solution to −4 or −5 deg.cent. and maintain at this temperature for one hour by pack-

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ing the flask in a mixture of ice and salt. Filter out the waxy hydrocarbons, using a funnel packed with ice and salt, and apply suction if necessary. Wash the flask and filter with about 25 cu.cm. of 95 per cent alcohol, which has been previously cooled in the same temperature. Catch the filtrate in a flask which is afterwards cooled to —4 or —5 deg.cent. to make sure that all possible waxy hydrocarbons have been removed, and refilter if necessary. Dissolve the residue on the filter paper with hot chloroform, into the original flask. Evaporate the chloroform and dry the flask to constant weight at 95-100 deg.cent.; cool in a desiccator and weigh.

*Hydrocarbons B*

18. Evaporate the alcohol from the flask containing the alcohol soluble unsaponifiable material add 25 cu.cm. carbon tetrachloride and transfer to a separatory funnel. Shake with conc. $H_2SO_4$, drain off the discolored acid and repeat with fresh portions of acid until there is no longer any discoloration. After drawing off all the acid, wash the carbon tetrachloride solution with repeated portions of water until all traces of acid are removed. Transfer the carbon tetrachloride solution to a weighed flask; evaporate off the solvent and dry the flask to constant weight at 95-100 deg.cent. Cool in a desiccator and weigh.

*Free Sulphur*

19. Add two grams $KNO_3$ to the aqueous solution and washings from the etherial separation of the unsaponified material. Evaporate to dryness in a silver or nickel dish and heat to quiet fusion, avoiding contamination with sulphur fumes. Transfer with water to an evaporating dish, acidify with HCl, evaporate to dryness, and dehydrate silica. Add 2 cu.cm. conc. HCl, take up in water, filter and wash, making a volume of 200 cu.cm. Heat to boiling and add slowly a slight excess of hot 10 per cent $BaCl_2$ solution. Allow to stand over night, filter, wash, ignite, weigh the $BaSO_4$ and calculate to sulphur.

*Definition of Terms Describing Compounds of Acetone Extract*

20. The difference between the Acetone Extract and the Free Sulphur shall be called the Organic Extract.

21. The difference between the Organic Extract, and the Unsaponifiable Material shall be called the *Saponifiable Acetone Extract.*

22. The sum of the Hydrocarbons A and B shall be called the total *Waxy Hydrocarbons.*

23. The difference between the Unsaponifiable Material and the Waxy Hydrocarbons shall be called *Unsaponifiable Resins.*

*Chloroform Extraction*

24. Extract continuously the residue from one of the acetone extractions, (without necessarily removing the acetone that may be on it), for four hours with 60 cu.cm. chloroform, using a weighed flask. Distill off the solvent and dry the flask and contents for two hours at 95-100 deg. cent. Desiccate until cool and weigh. Continue to dry for one hour periods until constant weight is obtained. In drying, place the flask on its side but at a sufficient angle from the horizontal so that the extract does not appreciably run down the side of the flask. (If it is needful to wait after the acetone extraction, before starting the chloroform extraction, the sample must be kept in a vacuum of at least 50 mm. of mercury.)

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*Alcoholic Potash Extraction*

25. Dry the residue from the chloroform extraction at 50-60 deg.cent., put into a 200-cu.cm. Erlenmeyer flask with 50 cu.cm. alcoholic KOH solution and boil for four hours under a reflux condenser. Filter the solution into a beaker and wash twice, using each time 25 cu.cm. hot absolute alcohol and then wash thoroughly with hot water. Evaporate the solution to approximate dryness, take up in warm water and transfer to a separatory funnel. Acidify with 15 cu.cm. 5 normal HCl, using this to rinse the beaker. Add sufficient water to make the bulk of the solution 100 cu.cm. When cool add 40 cu.cm. ether, using it to rinse the beaker in 20-cu.cm. portions. Shake the aqueous and etherial solutions thoroughly. After complete separation, draw off the aqueous solution and treat in another separatory funnel, with a fresh 20-cu.cm. portion of ether. Continue to shake the aqueous solution with fresh portions of ether until a colorless portion has been obtained, then shake out twice more. Unite the etherial solutions and wash with successive additions of water, continuing twice after the water shows no acid reaction. Filter through a plug of extracted cotton into a tared flask, wash the filter and funnel with ether, evaporate the ether without boiling and dry the residue to constant weight at 95-100 deg.cent. Cool in a desiccator and weigh.

*Fillers*

26. Extract a 1-g. sample with acetone for five hours. Transfer the residue to a tall lipped 200-cu. cm. beaker, add 40 cu.cm. terebene and 20 cu.cm. xylol and heat on an oil bath at 105-110 deg.cent. for about 20 hours, or until the bulk of the fillers settle promptly after stirring. Occasional stirring will aid the solution. Allow the beaker to stand until the fillers and undissolved residue have settled thoroughly and decant the supernatant solution into a beaker. Add to the undisturbed residue 30 cu.cm. terebene; heat for several hours, allow to settle, decant, unite the decanted solutions and repeat this treatment as long as there is any indication of rubber being present. Continue to heat the decanted solutions during the further treatment of the undissolved residue and filter them through a tared filter paper. This filter paper must be of close texture and shall have been washed with terebene, alcohol and acetone. The tare filter shall be treated with the same solvents and dried in the same manner throughout the analysis as the filter containing the residue. Weigh all filter papers in weighing bottles of sufficient size to take them without folding. Refilter if mineral matter runs through. Wash the beaker that contained the decanted solutions and the filter paper, with benzol, using a second beaker to catch the filtrate. Add benzol to the beaker containing the residue, heat and after settling decant, repeating this treatment with benzol until it is thoroughly washed. Filter and wash well with benzol. Wash in the same manner both beakers with hot alcohol and then transfer the residues to the filter paper, using hot alcohol and an acetone extracted policeman. Wash finally with acetone. Dry in air at 95-100 deg.cent. and weigh. Again wash the filter paper and contents with benzol and alcohol, dry, weigh and repeat this treatment until constant weight is obtained. Evaporate all the filtrates and washings, transfer to a porcelain dish, burn off and weigh. Add this amount to the fillers found above. If this ash is greater than 1 per cent, the entire

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determination shall be repeated. Subtract 0.5 per cent as anarbitrary value for the amount of organic matter from the rubber retained with the fillers.

*Sulphur in Fillers*

27. Transfer the fillers from the filter paper into an iron crucible; burn the filter paper and add the ash to the crucible. Add the Total Sulphur flux and proceed with the determination of sulphur as in Section 28, Total Sulphur. Subtract the percentage of sulphur found from the percentage of fillers to determine the percentage of fillers free from sulphur.

*Total Sulphur*

28. Mix a 0.5-g. sample with 4 g. $Na_2O_2$ and 6 g. $K_2CO_3$ in a dry 15-cu.cm. iron crucible. Cover and heat gradually until the mixture fuses, proceeding cautiously, as rapid heating will cause an explosion, and then bring to quiet fusion for 15 to 20 min. Apply the heat so as to avoid contamination with sulphur fumes. Rotate the crucible while the melt solidifies. When cool, put crucible and cover into a casserole containing 200 cu.cm. of water; add 5-10 cu.cm. bromine water and boil until the melt is dissolved. Allow the precipitate to settle, decant the liquid through a thick filter and wash the residue with hot water. Acidify the filtrate with HCl, evaporate to dryness and dehydrate silica; add two cu. cm. conc. HCl., take up in water, filter and wash, making the total volume about 400 cu.cm. Heat to boiling and add slowly a slight excess of hot 10 per cent $BaCl_2$ solution. Allow to stand over night, filter, wash, ignite, weigh the $BaSO_4$ and calculate to sulphur.

*Specific Gravity*

29. The specific gravity shall be the ratio of the weight of a given volume of the rubber, to the weight of an equal volume of water, both at 20 deg.cent. Cut strips of the largest applicable size from the conductor and use about 5 g. for the sample. Determine the specific gravity in the usual manner by means of a specific gravity bottle. Care must be taken that no air bubbles adhere to the sample.

*Checks*

30. Specific gravity determinations shall check within 0.01. The other duplicate determinations shall check within the following limits expressed as percentages of the original sample.

| Determination | Check |
|---|---|
| Acetone Extract | 0.10 |
| Saponifiable Acetone Extract | 0.10 |
| Unsaponifiable Resins | 0.10 |
| Waxy Hydrocarbons | 0.10 |
| Free Sulphur | 0.05 |
| Chloroform Extract | 0.10 |
| Alcoholic Potash Extract | 0.10 |
| Fillers, free from sulphur | 0.50 |
| Total Sulphur | 0.10 |

*Interpretation*

31. The *Rubber* shall be considered to be the difference between 100 and the sum of the Waxy Hydrocarbons, Total Sulphur and the Fillers (free from sulphur), expressed as percentages. If the Chloroform Extract is over 3.0 per cent of the rubber so calculated, subtract the excess from the Rubber. If the KOH extract is over 1.8 per cent of the Rubber, as first calculated, subtract this excess also from the Rubber.

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*Carbon and Red Lead*

32. Heat about one g. of the sample with 30 cu.cm. conc. $HNO_3$ and 15 cu.cm. water. A black insoluble residue indicates the presence of carbon.

When the rubber is dissolved, in the fillers determination, the absence of any red particles indicates the absence of red lead. If red particles are present, dissolve another sample by the same method as the fillers (Section 26), filter the solution into a Gooch crucible and wash thoroughly. Remove the felt and residue to a distilling flask, add HCl, and distill over the chlorine liberated by the lead peroxide, absorbing the gas in a solution of KI and starch. Not more than 0.1 cu.cm. $\frac{N}{10}$ thiosulphate shall be required to titrate the iodine liberated.

*Statement of Results*

33. The results of the analysis shall be stated in the following form:

| | Per cent |
|---|---|
| Acetone extract | |
| Saponifiable acetone extract | |
| Unsaponifiable resins | |
| Waxy Hydrocarbons | |
| Free sulphur | |
| Chloroform extract | |
| Alcoholic Potash extract | |
| Fillers free from sulphur | |
| Total sulphur | |
| Rubber | |
| Color of acetone extract (60 cu.cm. vol.) | |
| Fluorescence in acetone extract solution (present or absent) | |
| Hydrocarbons A (consistency and color) | |
| Hydrocarbons B (solid or liquid) | |
| Color of chloroform extract (60 cu.cm. vol.) | |
| Carbon (present or absent) | |
| Red Lead (present or absent) | |
| Specific Gravity | |

## PART III—EXPLANATION OF PROCEDURE

*General*

1. The Committee felt the more acceptable solution of its problem of drawing up a procedure which would give the percentage of rubber present in a compound with a reasonable degree of accuracy, to be the perfection and amplification of the difference method rather than the development of a direct method, which if equally correct, might not inspire confidence because of the comparative novelty of its application to this purpose.

2. The most feasible means of limiting the kind of rubber, was considered to be the determination of the saponifiable and unsaponifiable resins. These are fairly constant characteristics of the resins of *Hevea* rubber, and of compounds made from the same. Other methods, such as the determination of the saponification number and the optical activity of the resins, were thought to be unpractical.

3. The method as developed is applicable to the analysis of any pure rubber compound containing only mineral matter with or without ceresine or paraffine wax, regardless of the kind or amount of rubber, and can

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be used in conjunction with other specifications provided the limits are changed to correspond with the amount and kind of rubber desired, and due consideration is given to interfering mineral matter. When applied to a compound without ceresine or paraffine wax the unsaponifiable acetone extract is the unsaponifiable resins.

4. The method has been definitely described, to make it certain that experienced chemists may obtain concordant results. The interpretation has been rigidly defined, obviating any ambiguity as to the meaning that will be assumed, even though this sometimes appears to be arbitrary.

*Sample*

5. In order to obtain uniform results, the Committee has established by experiment that a definite method of sampling has to be adopted and that for all extractions the sample must be reduced in a prescribed manner to at least an approximately similar degree of fineness. For this reason the procedure specifies a definite type of grinder obtainable in two forms, and also specifies definite sieves.

*Extraction Apparatus*

6. The Committee has proved that the extraction apparatus used by different chemists must be of exactly the same form and the same size. It was also proven that small samples in the apparatus give the maximum results and that the rate of extraction is dependent upon the amount of solvent and its temperature as it passes through the sample. The apparatus finally adopted combines the advantages of several forms that were studied and together with simplicity of operation and adjustment to uniform conditions, gives practically complete extraction when used as specified. A number of other variations that might have a possible effect upon the amount of extract, were tried but found to be inappreciable.

*Acetone Extraction*

7. The extraction is made within 24 hours of the preparation of the sample, so obviating any appreciable oxidation. Two samples are extracted and united, so that a larger amount of extract may be obtained for the subsequent separations, and the extraction apparatus kept within a convenient size. Hot chloroform is used to facilitate the complete transference of the extract. The flasks are placed on their sides when drying, to hasten the emission of the solvent and thus reduce chance of volatilizing, through longer heating, some of the more volatile constituents of the extract. Drying in vacuo at room temperature, does not remove all the moisture if paraffine is present and such drying with heat or at 100 deg. cent. in an inert gas, presents no practical advantage over the method given.

*Separation of the Acetone Extract*

8. The method given was devloped so that all the desired constituents could be determined on one sample.

9. Emphasis is laid on thorough extraction of the unsaponifiable material and the retention of the flocculent material with the etherial solution. This latter material is not soluble in either ether or water, but it was proven that if such as was chloroform-soluble was included in the unsaponifiable material, the subsequent determination of the hydrocarbons would be more exact. A portion of this flocculent material is insoluble in chloroform.

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10. The hydrocarbons are determined in two places, making an approximate separation between the solid and the liquid ones, if both are present. The first hydrocarbons (A) are those insoluble in the solvent at a low temperature. The presence of unsaponifiable resins in the solution prevents the more complete freezing out of the hydrocarbons, but the remainder is obtained after treatment of the resins with sulphuric acid. In this way, chance of loss through the action of the acid has been largely eliminated.

11. The method for free sulphur gives all the sulphur in the acetone extract with the exception of negligible amounts which may be in the unsaponifiable material. It was proven that the results agree with determinations made directly on other acetone extracts.

12. The saponifiable and unsaponifiable resins are obtained by difference.

*Chloroform Extraction*

13. The chloroform extraction should be made at once after the acetone extraction, or the sample put in a vacuum, so as to avoid the danger of an abnormally high extract. When the extract is dried as specified, constant weight is obtained before any appreciable oxidation occurs. If bituminous substances are present, that portion which has not been extracted by the acetone, will be largely soluble in chloroform and can be readily distinguished by its color. The amount of extract is also affected by the presence of uncured rubber and rubber of low degree of polymerization. A properly cured *Hevea* compound will always give a little extract with chloroform, which varies somewhat with the method and conditions of cure.

*Alcoholic Potash Extraction*

14. The alcoholic potash extraction is the usual saponification process for obtaining the fatty acids of rubber substitutes. The total amount of such substitutes is not obtained, but if any appreciable amount is present, the value will exceed that of the limit allowed. When no substitutes are present, this determination always yields a small amount of extract from *Hevea* rubber.

*Fillers*

15. Since the rubber is determined by difference, it is necessary to determine the amount of fillers. Ashing the compound gives accurate results provided no volatile or decomposable fillers are included. This, however, cannot be assumed to be the case. The determination of fillers by using solvents to dissolve the rubber, has always presented a difficult problem and it is only after a great many experiments that the Committee can report a reasonably satisfactory method.

16. Many kinds and probably every class of rubber solvents were tried, with the result that some did not completely dissolve the rubber at low temperatures and ordinary atmospheric pressure; others appeared to dissolve the rubber, but formed a colloidal solution holding some of the fillers which could neither be filtered nor centrifuged clear of mineral matter, and the ones that did not present these difficulties consumed much time.

17. Terebene was found to be the solvent which would most completely dissolve the rubber and after continued heating would completely destroy the rubber in solution as such, and so break up the colloidal solution. Filtering out the mineral matter is then a comparatively simple

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process. The treatment with terebene must be performed in the presence of air to break up the colloidal solution. A disadvantage of using terebene is the length of time required to obtain satisfactory solution. The speed is greatly hastened if at first xylol is used with the terebene. After decanting this solution, terebene is used alone. The rapidity of the action is also hastened by increasing the temperature. That specified gives reasonable speed without serious danger of carbonizing the rubber or of losing any of the fillers by decomposition.

18. It was proven that there is organic matter derived from the rubber, which is insoluble in the solvents and remains with the fillers. Without taking this into account, the fillers will appear high, and the rubber by difference, low. As this organic matter was proven to be largely proteid matter, and this was originally a part of the rubber, an allowance is made for it. This is the amount generally retained when the method is carried out as specified. It is possible, by centrifuging, to throw out of the solution a great deal more than this, and it is also possible to determine the approximate amount retained in each case, but the slight increase in accuracy does not justify the extra determination.

19. Most of the details of this procedure are self-evident, but it is probably worthy of note that the benzol solutions are filtered into a separate beaker, as otherwise the benzol is apt to precipitate, from the terebene solution, organic matter which may be mistaken for mineral matter or conceal mineral matter passing through the filter. The filtrates are ashed since traces of mineral matter are always found in them. Emphasis must be laid upon the necessity of conducting blanks on the solvents.

*Sulphur in Fillers*

20. The sulphur in fillers is determined in order to calculate the rubber by difference. It is carried out only on the fillers obtained on the filter paper, the sulphur in the ash from the filtrate and washings, being negligible.

*Total Sulphur*

21. Several methods for total sulphur were tried. The method given was found to yield accurate results.

*Interpretation of Results*

22. Emphasis is laid on the method of calculating the results. The saponifiable acetone extract and the unsaponifiable resins are considered to be parts of the rubber. The chloroform and alcoholic potash extracts, when within the limits specified, are also so considered. It has been explained that the proteid matter with the fillers has been allowed for, since it also is a part of the rubber. The fillers are calculated sulphur-free, so that the sulphur will not be subtracted twice. No allowance is made for the ash in the raw rubber as it is considered to be negligible. This method of calculation has to be adopted if the rubber found is to agree with that originally put into the compound.

*Moisture*

23. A determination of moisture is not given, as electrical tests will detect its presence if in excess. If electrical tests are required, the error introduced by the omission of this determination, is very small.

*Note*: With a procedure of this length it is impossible to explain every detail without undue elaboration and the Committee wishes to point out

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that while to experienced chemists the procedure may seem overburdened by detail, yet every specified detail was found necessary in order that the conditions essential to accurate and consistent work might be reproduced by all chemists using the procedure. For this reason it is extremely important that all instructions be observed even if their significance is not perceived by the individual chemist. It will probably be found that even with the instructions properly observed, some experience will be needed to apply the method successfully.

PART IV—SPECIFICATION FOR 30 PER CENT HEVEA RUBBER COMPOUND

1. A 30 per cent fine *Para* or smoked first latex *Hevea* rubber compound with mineral base, shall be furnished. It shall contain only the following ingredients:

Rubber.
Sulphur.
Inorganic mineral matter.
Refined solid paraffine or ceresine.

2. It shall not contain either red lead or carbon.

3. The vulcanized compound shall conform to the following requirements, when tested by the procedure of the Joint Rubber Insulation Committee.

(a) Results to be expressed as percentages by weight of the whole sample:

| | Maximum | Minimum |
|---|---|---|
| Rubber | 33 | 30 |
| Waxy hydrocarbons | 4 | .. |
| Free sulphur | 0.7 | .. |

(b) Results to be taken between the limits given in proportion to the percentage by weight of rubber found:

| *Limits allowed for 30 per cent Rubber Compound.* | Maximum | Minimum |
|---|---|---|
| Saponifiable acetone extract | 1.35 | 0.55 |
| Unsaponifiable resins | 0.45 | .... |
| Chloroform extract | 0.90 | .... |
| Alcoholic potash extract | 0.55 | .... |
| Total sulphur (see note 2) | 2.10 | .... |
| Specific gravity | .... | 1.75 |
| *Limits allowed for 33 per cent Rubber Compound.* | | |
| Saponifiable acetone extract | 1.50 | 0.60 |
| Unsaponifiable resins | 0.50 | .... |
| Chloroform extract | 1.00 | .... |
| Alcoholic potash extract | 0.60 | .... |
| Total sulphur (see note 2) | 2.30 | .... |
| Specific gravity | .... | 1.67 |

4. The acetone solution shall not fluoresce.

5. The acetone extract (60 cu.cm.) shall be not darker than a light straw color.

6. Hydrocarbons shall be solid, waxy and not darker than a light brown.

7. Chloroform extract (60 cu.cm.) shall be not darker than a straw color.

8. Failure to meet any requirement of this specification will be considered sufficient cause for rejection.

9. Contamination of the compound, such as by the use of impregnated tapes, will not excuse the manufacturer from conforming to this specification.

*Note* 1: This specification shall be supplemented by appropriate

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clauses relating to tensile strength, elasticity, insulation resistance and dielectric strength.

*Note* 2: The limit on total sulphur may be omitted at the option of the purchaser. See Part V of Report.

PART V—EXPLANATION OF SPECIFICATION

1. Experience has shown that compounds which upon analysis, show the characteristics of good *Hevea* rubber, may be relied upon to be more permanent than those made of rubber of other grades. It is not affirmed by the Committee that a compound which conforms with this specification, is necessarily permanent, or that a better compound cannot be made, but it is believed that enforcement of the specification will limit the use of inferior materials and that it will put the manufacturers more nearly upon an equality of endeavor, where they can use their experience to obtain the best results. Used in connection with the analytical procedure, the specification will enable purchasers to order a good compound and to ascertain with a greater certainty than heretofore, whether the material received, represents the compound specified.

2. The term *Hevea* applied to rubber means rubber from the *Hevea Brasiliensis* tree whether wild or cultivated and regardless of the locality in which it has been grown. *Para* rubber is *Hevea* rubber which has been shipped from the port of Para, Brazil, and comes in several grades. Smoked first latex *Hevea* rubber is a high grade of plantation rubber which is collected prime and consists entirely of rubber which has risen in the settling vats. It is coagulated chemically and smoked in order to give it a hard cure, which ensures the greatest durability. The rubber required by this specification should be *Hevea* rubber of good quality, such a *fine Para* or smoked first latex plantation rubber.

3. Carbon is excluded because it is considered, by some purchasers, to be deleterious.

4. Red lead is excluded because of the possibilities of its deleterious effects on the rubber.

5. Ozokerite is prohibited because the acetone extract obtainable from it interferes with the separation of the acetone extract obtainable from the rubber, thereby vitiating the assay of the rubber extract. This prohibition is unimportant to the manufacturers, as ceresine, which is permitted, is the essential constituent of ozokerite.

6. An upper limit is placed upon the rubber in order to prevent the attainment of electrical and mechanical strength by the use of an extra quantity of inferior rubber whose lasting qualities might not be satisfactory.

7. The hydrocarbons are limited owing to their tendency to separate from the compound and thus possibly cause porosity.

8. The free sulphur is limited because an excessive amount may be deleterious.

9. The maximum limit on the saponifiable acetone extract is to prevent the use of raw or reclaimed rubber with high saponifiable extract. The minimum limit assists in forcing the use of *Hevea* rubber, since it is characteristic of the acetone extract from *Hevea* rubber to be largely saponifiable.

10. The unsaponifiable resins are limited because a low proportion of unsaponifiable resins is characteristic of *Hevea* rubber. A high result might be due to the presence of reclaimed rubber.

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11. The chloroform extract is limited, first to prevent the use of bituminous substances, and second, to limit depolymerized and undercured rubber.

12. The alcoholic potash extract is limited to prevent the use of saponifiable rubber substitutes.

13. The specific gravity is limited to reconcile the specification of ingredients by weight with the practise of purchasing material by volume.

14. Fluorescence of the acetone solution is prohibited as it indicates the presence of mineral oils.

15. The color of the acetone extracts is specified to conform with the normal color of the extract from *Hevea* rubber. A darker color indicates adulteration or an inferior grade of rubber.

16. The hydrocarbons are required to be solid in order to prevent the use of oils and paraffine of low melting point. The shade required is that obtained from paraffine wax or ceresine. If hydrocarbons B are liquid this would indicate reclaimed rubber softened with mineral oil, or a poor grade of paraffine.

17. The color of the chloroform extract is specified to conform with the color of dissolved gum in minute quantities. The presence of bituminous substances would be indicated by a brown or black color.

18. It would be desirable that the sulphur of vulcanization be limited to exclude reclaimed rubber, which contains the sulphur of its previous vulcanization, but the Committee has not yet developed an acceptable method for determining this quantity. It is, therefore, confronted with the choice of either placing a limit on the total sulphur or giving up the attempt to exclude shoddy by sulphur limitation. Option is therefore given to the purchaser to insert or omit the limit on total sulphur. Such insertion will at times exclude reclaimed rubber and the Committee believes it possible to make a suitable compound with this limitation. The Committee thinks that a sulphur limit positively excluding reclaimed rubber, would place too great a hardship, in other ways, on the manufacturers. Where the specification is used with no total sulphur limit, the use of many kinds of, or much, reclaimed rubber, will be guarded against by the limits of the various components of the acetone extract. When the limitation on total sulphur is omitted, sulphur-bearing fillers, which possess certain advantages, may be used.

19. This specification should be supplemented by appropriate elasticity and tensile strength tests, in order to add to the assurance that good rubber has been used and that the vulcanization process has been properly carried out; also by appropriate electric stress and resistance tests, to assure proper insulating qualities and homogeneity of structure. The exact values of the limits for these tests will depend upon the use to which the material is to be put.

JOINT RUBBER INSULATION COMMITTEE

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MR. W. B. GEISER, MR. H. B. RODMAN,
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OCTOBER 1, 1913.

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# OUTDOOR VS. INDOOR SUBSTATIONS

BY ALEXANDER MACOMBER

ABSTRACT OF PAPER

The development of the outdoor substation vs. the indoor type is an interesting commentary on the adaptability of engineering progress to new fields and the subject is briefly recapitulated in this paper, in line with the developments and application of this branch of transmission work.

The causes for development of this apparatus, together with a general description of the classes of apparatus involved which have been changed to meet new conditions, are given. The application of the indoor vs. the outdoor substation to services of different character is indicated, and the tendencies for the future briefly touched upon. A comparison of the advantages and disadvantages of the types considered is outlined.

In general, it appears that the equipment for outdoor installations has been successfully developed to meet the severe conditions imposed, and the numerous installations involving outdoor features indicate the extensive use of this idea in the future, while its development as applied to the central station itself affords a considerable field for attention.

THE DEVELOPMENT, in the last half-dozen years, of the outdoor substation vs. the indoor type, with its attendant problems, is a most interesting commentary on the adaptability of engineering progress to new fields. Primarily, as in most such cases, the cause was an economic one, the desire to serve from transmission systems the small consumer who could not be reached on account of the excessive first costs of installation.

The development of suitable apparatus to meet this fundamental condition has opened up a new field for substation development and progress along engineering lines necessitated by new and peculiar conditions has indeed been remarkable. These problems, especially in reference to the class of work which introduced them have been well solved, but the possibilities in application to larger and broader fields has meant attacking problems of a far more complex nature. The success obtained justifies the expectation that outdoor substations will occupy a very important position in the development of transmission work. The extent, however, to which it is desirable to develop these propositions, must receive serious consideration dependent



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on the engineering features of design and operation, and fundamentally on the economics of the problem.

This matter has been ably discussed previously, but its importance is such that it is proposed to briefly recapitulate the subject in view of its developments and possible applications, trusting that discussion of practical experience will be afforded.

## Development of Equipment

To meet the engineering conditions of outdoor operation, considerable experimental work has of course been necessary, and results indicate that there is nothing inherent in the requirements of apparatus for these conditions which apparently cannot be successfully met.

The classes of apparatus involved which have required development to meet new conditions may in general be grouped under (1) protective equipment, (2) transformers, and (3) control equipment.

## Protective Equipment

The most important protective apparatus affected by outdoor installation is the electrolytic lightning arrester, which offers the most complete protection available at present for high-tension lines. Heretofore it has been necessary to protect this equipment by housing, but the development of low temperature electrolyte, together with other details of design, makes it now feasible to place the entire equipment out of doors, even under the most severe climatic conditions. The winter season when the severest temperatures are encountered, is also, as a rule, free from lightning disturbances, though it is important to secure continuous service of protective devices of this nature on account of surges occurring on the lines, the necessity being particularly noted where the switching of the high-tension systems is liable to cause serious line disturbances and consequent breakdowns at weak points. It is as much the function of the arrester to absorb these disturbances as to avert the direct effects of lightning itself.

## Transformers

The operation of outdoor transformers is no longer experimental. The principal difficulty to be met is the climate with its changes in temperature and atmospheric conditions. In general the outdoor type of transformer is similar to the indoor type except that the cover and leads are designed to shed moisture and provide the necessary higher factors of safety.

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Both self-cooled and water-cooled transformers are applicable to this service, with due consideration of its requirements. In the former case, grades of oil suited to the conditions are of course necessary, the only serious difficulty being on account of possible freezing. As a rule the load of the transformers will keep the oil sufficiently warm, but it is important that precautions be taken in order to prevent condensation of moisture. If necessary this is accomplished by small heating coils installed in the tops of the transformers. The freezing of the oil itself in idle units or under severe conditions may also be guarded against by the installation of external heating devices under the casings.

This freezing of the oil may be serious, particularly if transformers are out of service, because on energizing them, dissipation of heat, with the oil frozen, is liable to be slow, and inasmuch as the temperature rise in large units is about 20 deg. cent., the windings might be injured before the oil is liquefied. Little trouble is experienced, however, as ordinarily oil will not freeze at a temperature above −15 deg. cent., and special grades solidify at a considerably lower point.

The use of water-cooled transformers involves similar precautions against moisture, with the addition of suitable protection to the water circulating system, although the water of itself, by its circulation through the transformers, would not freeze except under severest conditions, provided the external connections are properly protected.

There apparently has not been much experience with air-blast transformers out of doors and it would seem that there might be a field for them as they do not offer the difficulties in giving climatic protection which are encountered with other types of transformers, provided moisture is kept out; and the cost would be less.

## Control Apparatus

The design of control apparatus, such as switches, circuit breakers, etc., has also met the severe conditions imposed, and outdoor switches of extremely high voltage are operating satisfactorily in severe sleet and snow storms. As with the other apparatus the general indoor types have been made suitable for outdoor service by perfection of details, such as enclosing the mechanisms, motor control, etc.

In general, then, it may be fairly stated that the use of the outdoor substation is not to be limited particularly by the lack of apparatus suitable for the severe operating conditions, and

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it is certain that even greater steps in the improvement of apparatus of this nature will occur.

## Application

The indoor substation has been highly developed to meet the various classes of service imposed upon it, and in fact has become very nearly standardized. It is hardly necessary to consider its development and status here, except as a comparison with those particular classes of service in which the outdoor substation may appear as its competitor, the advisability of the latter depending on a careful consideration of the various advantages and disadvantages as compared with the established type of indoor substation.

Generally speaking, for the purposes of considering outdoor installations, substations may be classified as serving the requirements of (a) small isolated loads, (b) large capacity loads, and (c) apparatus auxiliary to central stations.

A brief discussion of these respective divisions will indicate some of the requirements and opportunities incidental to each.

## Small Isolated Loads

It is along the lines of small isolated loads that the development of the outdoor substation first started, and which has afforded its greatest field to date.

Complete outdoor installations up to a few hundred kv-a. have enabled service to be given to isolated customers and small communities which otherwise could not be profitably served directly off the main transmission lines. It is possible to locate such substations almost anywhere, the structural and foundation requirements varying with conditions. The simplicity of design and construction has meant a small investment and a minimum of operating troubles. High-tension switching is usually limited to air-break types, instead of the costly oil switches, while lightning protection is afforded either by the electrolytic lightning arrester or the cruder horn type. Most such installations have been free from elaborate secondary control, that provided being, if any, of the simplest type established in weatherproof housings. There can be hardly any question as to opportunities for this type of station, and its rapid adoption and extending installation, on account of the factors of simplicity, low cost and lack of attendance, indicates the importance of its field.

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## Large Capacity Loads

The application of the outdoor substation to large capacity installations, particularly where the secondary control is split up into various circuits with more or less auxiliary apparatus, confronts us with larger problems. The substation may combine not only the functions of a switching station, but also that of supplying a large load to a community, and in general its location would not be affected by the type adopted, provided sufficient space is available.

With substations of this character, involving attendance, it is necessary to provide a suitable building designed for at least part of the installation. What part of the high-tension apparatus may properly be installed out of doors depends largely on the saving thereby effected. The actual outdoor apparatus must be provided for separately, and a combination of the indoor and outdoor substation will in many cases prove most advantageous. In some cases it is feasible to place the whole outfit out of doors, including the low-tension control equipment, provided the latter is not extensive, but in most cases it is questionable whether the operating features will permit this extreme. In cases where attendance is required it is certainly advisable to install the secondary equipment indoors.

The manner of installing the outdoor equipment will, of course, depend upon the size and importance of the layout. In general the incoming and outgoing lines must have proper terminal structures for connection and distribution to the banks of transformers. The transformers themselves should be provided with proper foundations, preferably of concrete, so designed that they may be removed on rails, and provision should be made for heating the cases if climatic conditions require it, while the piping for oil or water must be carefully considered.

The installation of lightning and control equipment is also subject, in general, to the same requirements.

A most important detail of the outdoor installation is that of providing proper facilities for repairing damaged apparatus, and large stations must provide some shelter where such repairs can properly be made.

The space occupied by the outdoor installation will, of course, be large, and adequate provision must be made for preventing anyone from coming in contact with the equipment.

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### Apparatus Auxiliary to Central Stations

Many central stations operated in connection with transmission systems have a considerable portion of their buildings given up to high-tension equipment and apparatus incidental to its operation.

The outdoor installation of such latter equipment would, in many cases, reduce the building cost materially, provided the extra outdoor space is available. The features of installation would be similar to those noted above. This phase of outdoor application is worthy of considerable attention and study.

### Comparisons

Considered generally, the following are the advantages and disadvantages of outdoor installations:

| Advantages | Disadvantages |
|---|---|
| Lower first cost | Repairs |
| Ease of extensions | Operating risks |
| Reduction of fire hazard | Danger to public |
| Simplicity of layout | Appearance. |

Reduction in cost was the cause for the development of this type of construction, is the reason for its continuance, and will govern its extensive application, when properly interpreted. For the small isolated substation of a few hundred kv-a., the cost will be from 25 per cent to over 50 per cent cheaper than the corresponding indoor station. For large installations, particularly where a building is provided for secondary control, the per cent of saving is much smaller, the less being the cost of the outdoor part of the installation in proportion to the total, the less being the saving due to this construction.

In connection with the cost, reduction of fire risk is important and outdoor service reduces this to a minimum.

The simplicity of either complete or partial outdoor installation is particularly attractive. With the intensive development of the indoor station we have succeeded in obtaining about all the elaborateness of design possible, and any development offering opportunity for simplicity of construction and operation should be welcome.

The disadvantages outlined have been mentioned generally in passing. The most serious ones are those of operation and facility for repairs. Experience indicates that operating difficulties are well overcome, and generally speaking, damage to modern apparatus is reasonably rare. Danger to outsiders can

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certainly be prevented by fencing, etc., while the matter of appearance is only of interest in certain localities.

## Summary

Summarizing the situation we find that the equipment for outdoor installations has been developed to meet the severe conditions imposed. Successful operation of installations of this character during several years shows that operating difficulties are unusual.

It is significant that at present there is installed, or under construction, approximately 300,000 kv-a. in high-tension outdoor type transformers. The query may well become, instead of " when shall we use the outdoor substation?" rather " when shall it *not* be used?" The cost is the main factor, although operating features with increasing high voltage become attractive on account of the simplicity of the layout and the tendency to make the high-tension equipment a part of the line itself.

The development of these ideas when applied to the central station itself should be as marked as it has been in the case of the substation, although the limits desirable to impose must in all cases be determined by the particular problem under consideration.

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# INDOOR AND OUTDOOR SUBSTATIONS IN PENNSYLVANIA

BY H. L. FULLERTON

ABSTRACT OF PAPER

This paper covers some points in substation design for installations for the lower voltages, including choice of location, type of building and arrangement of electrical apparatus.

The subject is treated in three divisions, namely: customers' substations fed from the distribution system, customers' substations fed from the transmission system and company's substations. Attention is called to some of the advantages of both the outdoor and indoor substations for each of the different divisions.

Points to be considered in the selection of locations for substations are outlined and several types of buildings, particularly the one of concrete slab construction, are described. Attention is also called to different arrangements of electrical equipments, which may be employed for installations of various sizes.

Different schemes for installing high-tension switchboard apparatus are considered, attention being called to the open wire and the cell structure installations, with special reference to the concrete cell structure and the method employed in its construction.

THE OBJECT of this paper is to cover in a general way outdoor and indoor substations of voltages up to and including 20,000, the limit being drawn at 20,000 volts because, where a higher transmission voltage than this is used, it is necessary to transform to a lower voltage on entering centers of population. I intend to call attention to some of the main points to be considered in determining the best location for substations for various purposes, to show some forms of substation buildings which can be used under various conditions, to give some of the advantages of the outdoor and indoor types, and to show some forms of electrical installations, which have been used to meet the various conditions which present themselves in substation design.

For convenience in handling the subject, I shall divide it into two general divisions:

1. Customers' substations, or those which are installed on



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the customer's premises and used only for feeding his service. This will be subdivided into:

(a) Those fed from the regular distribution system.

(b) Those fed from the transmission system.

2. Company's substations, or those which are installed by the company at a center of load and used to deliver service at a reduced voltage to the consumers within that district.

### Customers' Substations Fed from Distribution System

Unless the customer is along the line of a low-tension distribution system, it is necessary to install a substation to serve him with low-voltage service. This substation may be of any size from a small transformer on a pole on the street, to a large capacity installation in a regular substation room, depending on the customer's load. The probable demand of the customer determines the type of substation to be installed, and whether it be fed from the primary distribution mains at a medium voltage or from the transmission system direct, at the higher voltage. It is impossible to handle some of the larger installations economically from the primary distribution system, which is usually between 2000 and 5000 volts.

Customers whose demands are small, are ordinarily served by installing a small transformer on a pole adjacent to their load. This installation is very simple and serves quite well, until the demand requires transformers which are too large to be conveniently handled in this manner, but 50 kw. is probably about the limit for this type of construction. When the demand is above this point, it is necessary to make some special arrangement to furnish his service. If the location is such that room can be secured on the customer's premises, the transformers can be nicely installed on ordinary wooden poles something after the manner shown in Fig. 1.

In this arrangement two poles are placed on 10-ft. (3-m.) centers and a platform built between poles. A very neat arrangement can be made of the wiring on both the primary and the secondary side and the construction can be made safe both mechanically and electrically. The platform is constructed by fastening a channel to each side of the pole by through bolts and building thereon a wooden floor. The limit for an installation of this kind is about three 50-kw. transformers.

Where greater capacity is required, it is often possible to set the transformers on a platform on the ground, enclosing them

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with a high fence, so as to guard against persons coming in contact with electrical apparatus.

If conditions are such that an outside location cannot be secured for the transformers, it is then necessary to procure an inside location and build a transformer vault or indoor substation. Of course, the customer wants the transformers located in the space that cannot be used for any other purpose, which is usually in the basement or sub-basement, and below the sewer level, while the rules of the National Board of Fire Underwriters require transformer vaults to be sewered, also ventilated to the outside air. It quite frequently happens that the building is nearly completed before the architect remembers that a transformer vault will be necessary, unless some representative of the operating company impresses very forcibly upon him the necessity of making provisions for the same. Then the only available location is in some out of the way corner, where the transformers must be taken in through important parts of the building, often down flights of stairs of costly construction and entirely unsuited for the passage of heavy apparatus. When a freight elevator is installed, it is usually so located that it is not available for handling the substation equipment.

If the architect has provided a transformer vault, it is usually about one-half the size that is necessary. In one particular instance that I recollect, the installed transformer capacity amounted to 1125 kw., while the space provided by the architect was 3 by 10 ft. (0.9 by 3 m.), in which he expected us to place both the transformers and switching apparatus. In case no vault has been provided, it is necessary for the operating company to make the installation, which must be made in accordance with the rules of the National Board of Fire Underwriters, hence, it is necessary for the company to construct its own transformer vault.

Fig. 2 shows a fireproof transformer vault which has been installed in a building in which the architect had failed to make provision for the transformers. This type of vault has given very good results, where used, and is quite pleasing in appearance and cheap and easy to construct. The vault is built up of concrete slabs 3 by 6 ft. (0.9 by 1.8 m.) and 2 in. (5 cm.) thick, and an iron door having similar dimensions. The slabs and the doors can be prepared in the shop at odd times and kept in stock for such cases. Two or three men can easily handle

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these slabs and erect the transformer vault in a short time. A vault of this type of construction can be made in any size from 3 ft. by 3 ft. (0.9 by 0.9 m.) and 6 ft. (1.8 m.) high, up, in multiples of three. It is portable, being simply held together at the corners by small angles and can readily be moved in case any change is being made which requires its removal. The bolt holes, etc., in the slabs are cast in at the time of preparation. As will be noticed from Fig. 2, this construction furnishes a convenient place for mounting oil switches, instruments, etc., so that the customer can operate his installation without going near the high voltage apparatus. Neither is the meter reader in any danger of coming in contact with high-voltage wires, when making his monthly calls.

When the customer builds his own transformer vault, which is usually of brick or terra cotta construction, it is often possible to have him build in the wall a slate slab to allow of the mounting of the switches and watt-hour meters in a manner similar to that shown in Fig. 2. The back of the slab should be mounted flush with the inside of the wall. Where the slab is mounted in a 13-in. (33-cm.) brick partition, the switch handles and instruments are well protected by the surrounding walls.

*Location of Transformers.* The following points should be observed in selecting a location for the transformers:

1. Position of customer's load.
2. Location of operating company's street mains.
3. Accessibility for delivering material.
4. Accessibility for operating company's employes.
5. Possibilities of ventilation and sewer connection.

In the selection of a location from the electrical viewpoint, the transformers should be installed as near as possible to the center of the customer's load, as this will give him the least investment in copper and the best regulation to his various tablet boards. The company's street mains should also be considered. It is very desirable, since the connection is usually made with underground cable, to have as short and straight a run for the cable as is possible.

The location of the transformer vault should be such that the material can be delivered with as little work inside the customer's building as is possible. It should also be such that the company's employes can have access at any hour of the day or night, in case of trouble on the system. Delays caused by inability to find watchmen or building superintendents are often

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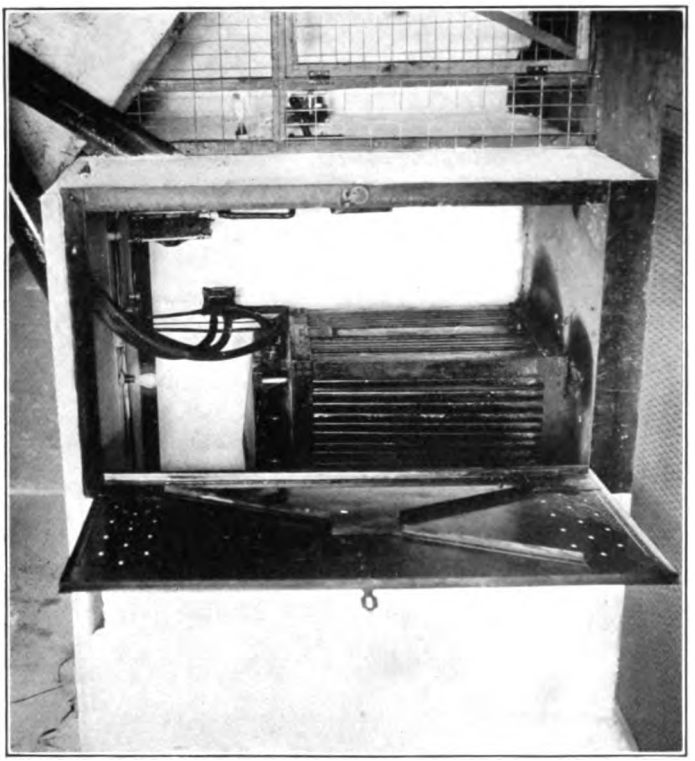

FIG. 2 [FULLERTON]

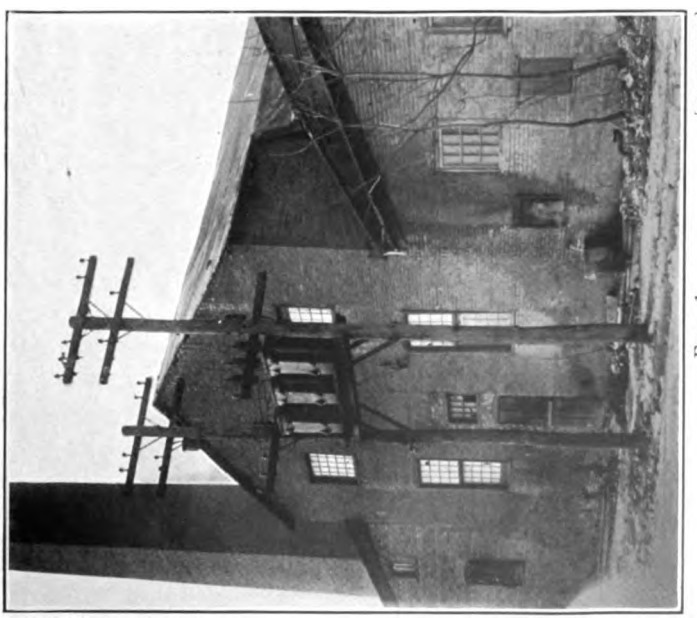

FIG. 1 [FULLERTON]

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FIG. 4 [FULLERTON]

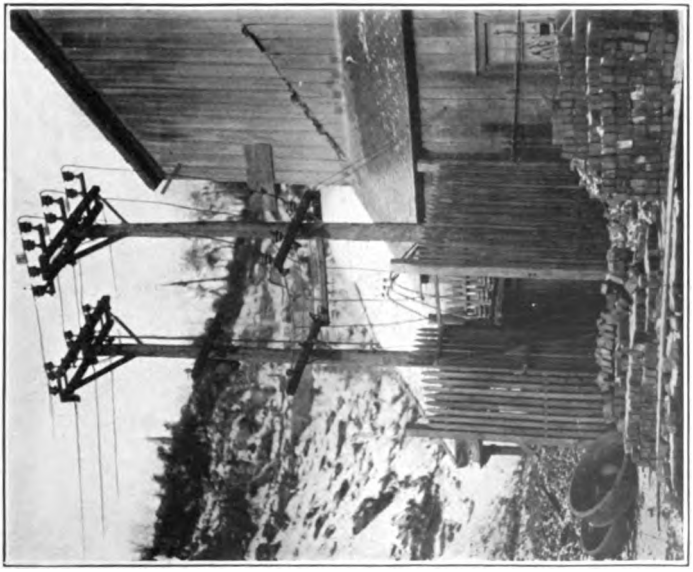

FIG. 3 [FULLERTON]

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quite serious. Since ventilation and sewer connections are required, it is necessary that this be taken into account in determining the vault location and a position should be selected that will lend itself to these requirements.

*Comparison of Outdoor and Indoor Installations.* Some of the advantages of the outdoor installations are:

1. Less cost for making installation.
2. Usually more accessible for company's employes in case of trouble.
3. Less difficulty in connection to company's lines.
4. No transformer vault required.
5. Better ventilation.

Some of the advantages of indoor installations are:

1. Apparatus more accessible for inspection or repairs.
2. Less danger of unauthorized persons interfering with apparatus.
3. Customer can have control of the installation on the primary side, by means of oil switches, if desirable.
4. Apparatus protected from weather.

CUSTOMERS' SUBSTATIONS FED FROM TRANSMISSION SYSTEM

When the demand of the customer is so great that he cannot be fed from the regular distribution system, it becomes necessary to install on his premises a substation to serve him from the transmission system, which may be of any voltage from 5000 up. Where space can be secured on the customer's property, it is often possible to supply him with service from an outdoor substation, installing switches, lightning arresters, fuses, etc., on poles and locating the transformers on a platform, on the ground, or on a suitable structural iron tower some feet above the ground.

Fig. 3 shows a 200-kw. outdoor installation in which the transformer is installed on a concrete foundation between two poles, on which are mounted the pole top switches, fuses, lightning arresters, etc., and around which is built a high picket fence with a couple of strands of barbed wire above the top of the pickets. Entrance is gained to the enclosure through a gate, which is kept locked. This is about as inexpensive an installation as it is possible to make and yet it has very satisfactorily furnished service to this brickyard for several years. The picket fence and barbed wires are even a better protection to the installation than mounting off the ground on towers,

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as shown in Fig. 4. Boys are not so apt to climb the picket fence as they are to climb the towers.

Fig. 4 shows an installation in which the transformers are mounted some ten or twelve feet above the ground on a structural steel construction, the top of the tower, like the poles in the previous case, being used for mounting the switching apparatus. This makes a very good arrangement up to the point where the transformers become too large to be handled readily.

Where it is not possible to secure outdoor space or when objection is made to the outdoor installation, the apparatus must be installed in a building either erected for the particular purpose or in one that is already constructed and can be used for the installation. Where the power is to be supplied to machines in a large factory, it is often desirable to enclose a small space for substation purposes in the building near the center of the load.

Fig. 5 shows the inside view of a substation erected in the center of a large screw and bolt works. The building is of steel and corrugated iron construction. The high-tension service is brought to the substation through cables supported from the roof of the building. By this arrangement, the substation was located near the center of the load and not only saved the customer considerable on his copper investment, but gave him good regulation to his motors, which would have been impossible with the substation located at one end of the factory, at a point which he had selected and at which point he was very determined the installation should be made. This customer is served with two high-tension lines, his running load being approximately 1000 kw. Three 375-kw., single-phase transformers controlled by automatic oil circuit breakers are used. The transformers are connected to the bus on both the high- and low-tension sides by disconnecting switches, thus enabling any one transformer to be cut out for either inspection or repairs without interrupting service. The customer's switchboard and motor-generator set are located in one end of the substation building.

In another case, where a substation was built in the center of a large steel mill, it so happened that the works were built on either side of a street, so it was possible to locate the substation in a very accessible point and still keep to the center of load. The substation was designed so that it would be able

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to handle the entire power requirements of the mill. When the installation was first made the demand was only about 400 kw., but they have been steadily increasing their demand until they now have connected about 2500 horse power and are making inquiries for more. Hence is emphasized the necessity for designing substations so that additions can be made from time to time as the customer's demand increases.

It is usually quite difficult to make the customer see that he should allow ample space in his substation, so that increase in size of apparatus can be made as his demand requires. Usually he thinks that his demand will be small and that you are requiring him to give up space much too large for your purposes.

Where the customer's demand is of any considerable size, it has been found quite desirable to install check meters on his service, the average of the two meters being taken as his consumption. When there is a difference of about 2 per cent in their readings, the meters are recalibrated.

The following points should be observed in selecting locations for and in designing customers' substations:

1. The installation should be as near as possible to the center of the customer's load.

2. The installation should be at a point where it will be least in the customer's way, and still be accessible to the operating company.

3. If outdoors, the installation should be wellen closed, so as to prevent unauthorized persons from getting into danger.

4. The design should be such that additions and repairs can be made to the equipment with the least possible interruption to the customer's service.

5. The design of the building should be such as to allow of the ready changing of transformers as demand requires.

6. The source of power should be such as to give him the most reliable conditions of service. Customers who are vitally effected by outages, should be furnished with emergency service.

7. Apparatus should be so arranged that the customer can handle his own switching at the direction of the operating company.

8. Installation should be made as well insulated and as nearly fool-proof as possible, since it is usually operated by men unfamiliar with high-tension current.

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*Comparison of Outdoor and Indoor Installations.* In customers' substations the field for the outdoor installations seems to be with the smaller isolated customer, where he has vacant space about his plant. Where the larger installations are made, the outdoor type does not seem so well adapted.

Some of the advantages of outdoor installations are:

1. No cost for new buildings.
2. No space required in customer's present buildings.
3. All high tension current kept outside of customer's buildings.

Some of the advantages of indoor installations are:

1. More reliable switching equipment can be installed.
2. Better facilities for inspection and repair.
3. Apparatus protected from weather.
4. Switching can be handled more easily by customer.
5. Less danger of accident to public.
6. Safer arrangement of apparatus possible.

## Company's Substations

Where the operating company generates its power at a large central station, which is usually at a point quite remote from the demand, or where it purchases power from some transmission company, it is necessary for it to receive current at a much higher voltage than that at which it can distribute to the small light and power consumers, hence, it is obliged to install a substation to transform the power from the transmission voltage to a lower distributing voltage. The size of this substation, of course, depends upon the character of the district to be served, which may be anything from a small suburban town, having a small demand, to the thickly populated power district having several thousand kilowatts demand.

When it has been decided that the time is ripe for a substation in a certain district, one of the most important and by no means the easiest problem is the selection of a location. Some of the points which should be considered in making a selection are:

1. Location of the present load.
2. Future development of the district.
3. Distance from existing substations on the system.
4. Outlet from the substation for the various feeders.
5. Street frontage.

The above points determine the geographical location for the substation in the district. It is not always best to locat

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in the center of the existing load, as the tendency may be toward development in one particular direction due to natural conditions in this section. Again the demand may be too close to an existing substation to warrant a second one, therefore, it may be advisable to locate to one side of the present load, and be in a better position to handle the growth outward from the present substations.

The outlet from the substation should be given considerable attention; if aerial lines are to be installed, a location such that it is possible to feed in at least two directions should be selected, and a corner lot would be preferable, where the lines could radiate from the substation in four directions. This means that the pole line from the substation will not be so heavily loaded as if only one outlet were available. Even though it be an underground district, it is quite desirable to have several outlets and save congestion in subways.

*Substation Buildings.*—Probably one of the least expensive buildings suitable for substation purposes is that made of structural steel and corrugated iron, but while this building is comparatively low in cost, its life is also comparatively short, and on the whole is not very desirable.

A type of building, which compares very favorably in cost with one of steel and corrugated iron, but which has much greater life, is shown in Fig. 6. This building is simply an enlargement of the slab transformer vault construction referred to earlier in this paper. It is built up of structural steel on which are bolted two-in. (5-cm.) reinforced concrete slabs of standard size; the roof is also made of these slabs, supported by the framework of the building. The concrete roof is covered by a tar paper and gravel roofing. About a six-in. (15.2 cm.) slope to the 12-ft. (3.6 m.) width is allowed. Steel sash, wire-glass windows and steel louvres are used. For air supply, a section of concrete is left off one or two of the lower slabs, leaving the expanded metal reinforcing exposed. This allows a free inlet of air and at the same time prevents large objects from entering. Regular $1\frac{1}{2}$-in. (3.8 cm.) expanded metal is used in the construction of the slabs.

This building compares very favorably in appearance with that of the average garage or out-building which may be found on back streets or alleys, and makes a fireproof construction. It is also portable and can be used to a good advantage at a location from which its removal at some future time may be

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desired. This building is 12 by 18 ft. (3.6 by 5.4 m.) and 15 ft. (4.5 m.) high. In it are installed three 250-kw. transformers serving four 2200-volt feeders.

Where a better type of building is required, brick or stone is usually used in the construction and as elaborate a design as is desired can be utilized. By the use of rock faced brick and sawed stone, a building very pleasing in appearance can be constructed at a reasonable cost.

The cost of buildings, or their equivalents, for substation purposes varies so widely, due to location and cost of labor, that it is impossible to give an estimate that would meet all conditions; however, I am giving a relative value to the various types, taking as a unit the least expensive installation-that with the outdoor apparatus installed on a concrete platform and enclosed by a fence.

| | | |
|---|---|---|
| Concrete foundations, poles, picket fence | (Fig. 3.) | 1.00 |
| Structural steel tower | (Fig. 4.) | 2.25 |
| Steel and corrugated iron building | (12 by 18 ft.) | 4.50 |
| Steel and concrete slab building | " " " | 6.75 |
| Ordinary red brick building | " " " | 15.00 |
| Rock faced brick and sawed stone | " " " | 25.00 |

*Substation Installations.* Like the buildings, the electrical installation has a very wide range of possible combinations. The outdoor substation is the cheapest, especially where no switching or regulating apparatus is required. However, it does not seem particularly well suited for installations where there is small apparatus such as instruments, oil switches, feeder regulators, etc., which should be housed. Of course, it would be possible to put the transformers and high-tension apparatus on the outside, erecting a building for the housing of the low-tension apparatus. Installations of this type have been made and work out very nicely for the small demands, but the present designs for outdoor switching apparatus for 10,000 and 20,000 volts are not such as to allow of very large installations being made along these lines.

It frequently happens that a transmission line may pass by a small hamlet or power customer from which a small revenue can be procured and still the income will not justify making a very expensive substation installation. This class of business can be taken care of by an outdoor substation. By an installation of this kind the town is furnished with electric light, which it may very much desire, and the operating company receives a small revenue from a district which would not allow

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of the installation of a regular substation building and apparatus. Fig. 7 shows an installation of this type. The transformers are mounted on a tower construction some feet above the ground. Pole top switches, fuses, etc., are used, no regulators or switches being installed on the low-tension side. If regulators are necessary, the outdoor pole type can be used.

Diagram *A*, Fig. 15, shows the wiring of this installation. The apparatus is connected to the transmission line through a switch and fuse; a choke coil and ground horn being inserted between the switch and fuse.

Diagram *C* shows the wiring of the installation made in the concrete slab building shown in Fig. 6. The transformers are protected by high-tension fused circuit breakers which also act as disconnecting switches for the incoming transmission lines, the transformers being connected direct to the high-tension bus. On the low-tension side each circuit is controlled by an oil switch and fuse. Lightning arresters are mounted on the poles outside the building.

Neither of the above installations can really be said to have a high-tension switchboard. This is scarcely necessary where the substation is small and is fed by only one or two transmission lines. Where the substation is important enough to have feeders from separate power houses, or where it is used as a switching station for high-tension lines, it is necessary to install some type of high-tension switchboard.

The simplest and probably the cheapest installation that can really be called a switchboard is the open wire type. Fig. 8 shows a fair example of this type of construction. The oil switches are mounted in concrete cells, while the busbars, disconnecting switches, etc., are mounted on framework above the switch structure. The spacings of the wires are kept at 12 in. (30.4 cm.) or better for opposite polarities. Cambric-insulated flameproof wire is used throughout. Disconnecting switches are installed on both the high-tension and low-tension sides of the transformers, so that one transformer can be disconnected without interfering with the service. Where open wiring is used, it is always painted a standard color, such as red for 11,000 volts, drab for 2200 volts and white for 110 volts, and this arrangement of colors is adhered to throughout the system.

Diagram *B*, Fig. 15, shows the wiring of a layout of this type. Both incoming and outgoing lines feed through oil circuit

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breakers to the high-tension bus. Disconnecting switches are always installed on each side of the oil breakers.

Fig. 9 shows, in section, the arrangement for a double bus open wire construction. The double bus arrangement is necessary where different combinations of high-tension lines are desired. This installation is very compact, yet all wires have ample clearance for both safety and ease of construction and repairs.

The next step toward safety is the use of the cell structure.

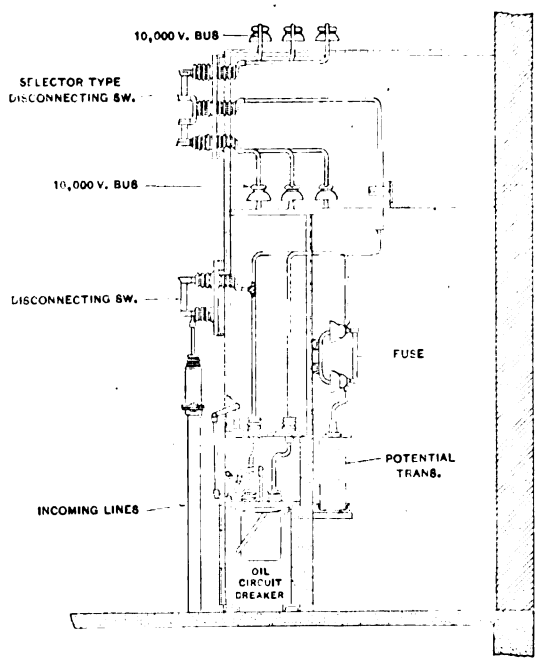


FIG. 9

In this arrangement all wires are separated by barriers of some description; soapstone, slate, concrete, ebony wood are some of the materials generally used. I will touch only on the use of concrete. This is probably the cheapest and gives a grounded surface for mounting the equipment, thus depending entirely upon the insulation of the apparatus.

When the cell structure is referred to, we usually think of something quite massive, but it is sometimes desirable to erect a cell structure and at the same time economize floor space.

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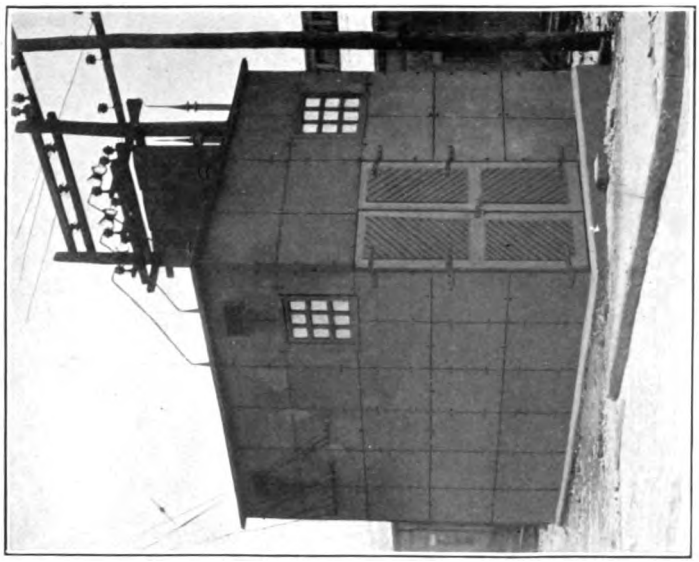

FIG. 6 [FULLERTON]

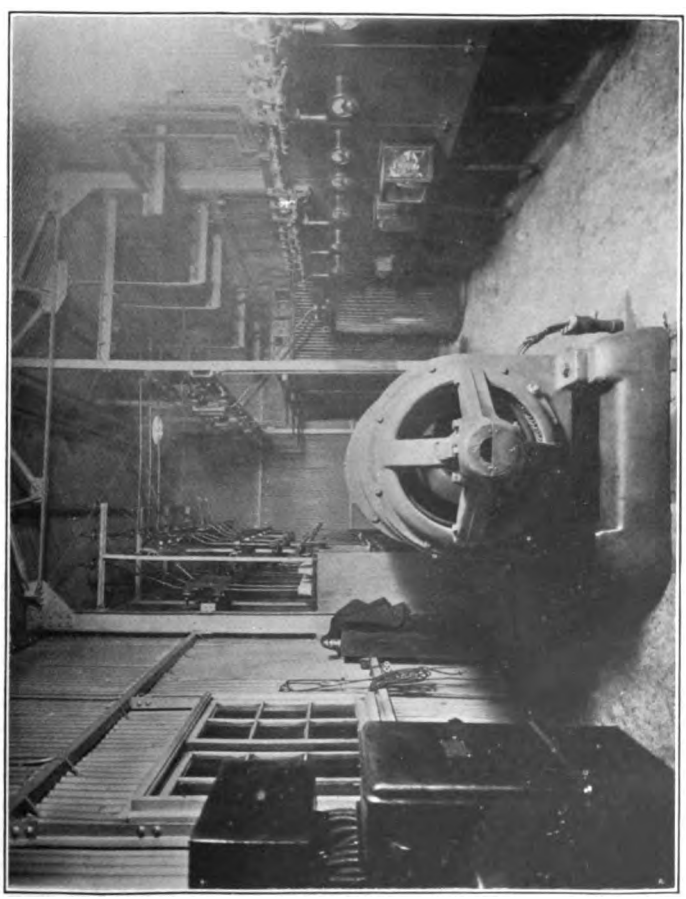

FIG. 5 [FULLERTON]

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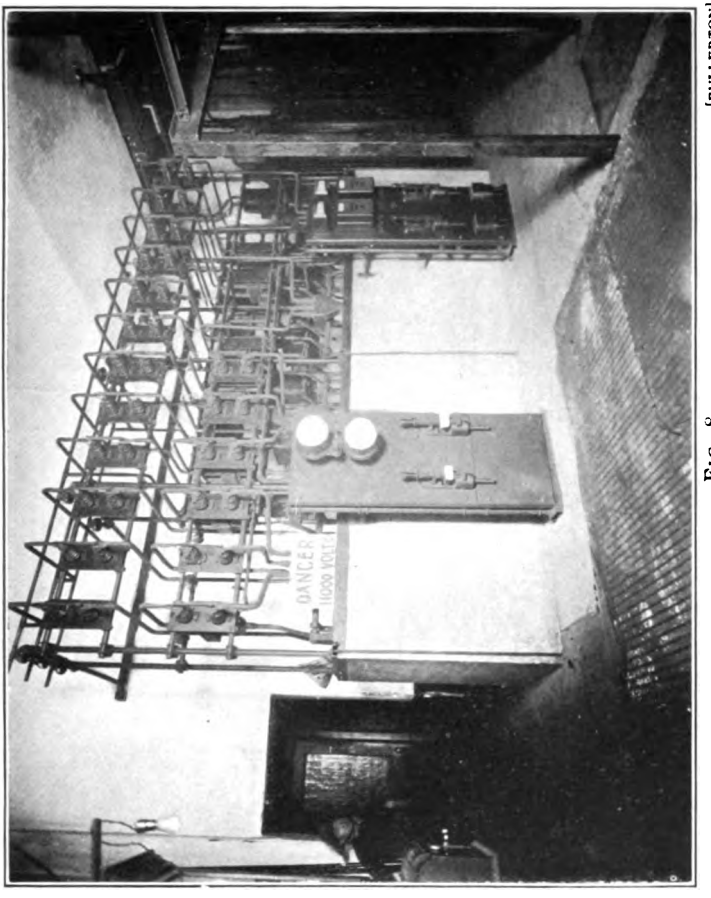


FIG. 8 [FULLERTON]

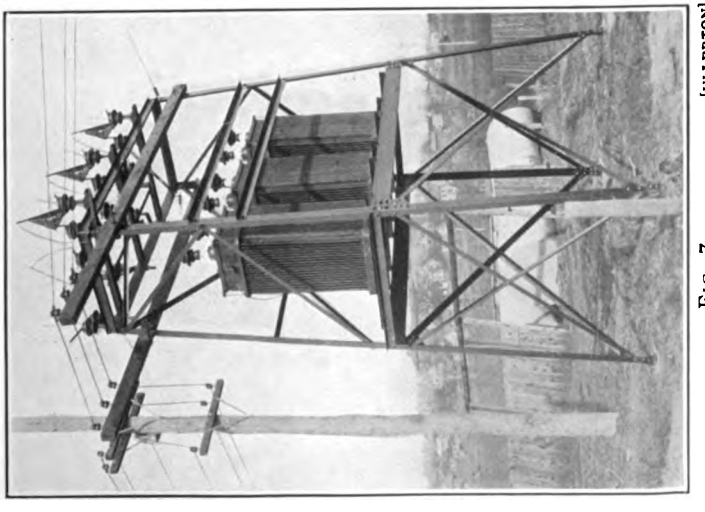

FIG. 7 [ULLERTON]

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Fig. 10 shows, in section, a double bus in stallationin which the busbars, series transformers, fuses and most of the disconnecting switches are mounted in compartments. The roof trusses are built through the cell structure, so that most of the available space is utilized. The lines enter through roof tubes between the vertical cell barriers. Connections to and from the oil switches are made with cambric-insulated wire

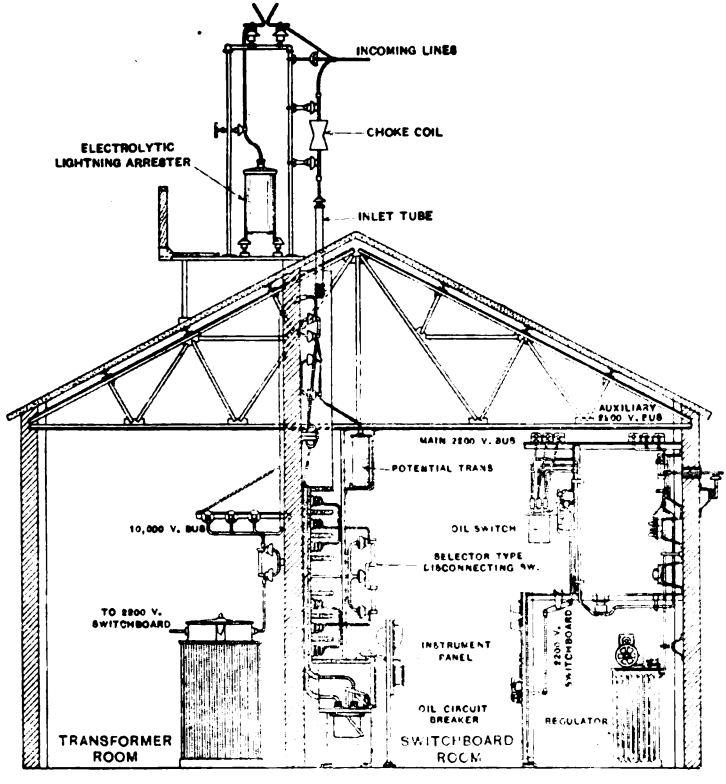


FIG. 10

in fibre conduit mounted in the concrete wall. To the right in the figure, the 2200-volt feeder switchboard, built in a double deck arrangement, is shown.

On the roof of the station are the outdoor electrolytic lightning arresters. A ladder is provided at the end of the building for use in getting to the roof to operate the arrester equipment.

Diagram *D*, Fig. 15, shows the wiring of this station. The

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lines feed in through oil switches to selector type disconnecting switches, and thence to each of the buses. One bus is sectionalized so that some of the lines ordinarily feed through to other substations entirely independent of the load in this station.

Figure 11 shows the inside view of this station, with the high-tension concrete structure to the left and the 2200-volt incandescent feeder switchboard to the right. In the construction of this feeder switchboard, remote control oil switches were used, which means all 2200-volt apparatus was kept away from the switchboard panels. Automatic voltage regulators were used on each feeder.

A more elaborate concrete structure is that shown in Figs. 12 and 13. Fig. 12 shows the front view of the concrete structure and Fig. 13 the section of a double bus switchboard. All circuits are connected to each bus through remote control oil circuit breakers. The insulators supporting the bus also make connection between the bus and the connections to the disconnecting switches. The switchboard panel is directly in front of each high-tension panel, thus allowing the use of hand-operated oil circuit breakers.

In the structure, notice the location of the oil switch at the bottom. This is made possible by the use of single-conductor lead cable clamped to the concrete and connecting the upper disconnecting switch with the oil circuit breaker. The horizontal barriers between buses are hung from the center web of the structure without any supporting posts at the outer edge. This allows of ready access to the buses. Space was also particularly valuable in this case, as is indicated by the position of the roof truss. Provision is made for adding larger switches in series with the present ones on the main floor at some future time. This switchboard serves not only for substation purposes, but is a distribution board for high-tension circuits to other substations.

Diagram *E*, Fig. 15, shows the wiring of this switchboard. All circuits are double-throw on either bus. The buses are sectionalized by disconnecting switches to allow of greater flexibility in switching. The transmission lines can be operated in multiple or separately, each one feeding its own section of load. By operating separately, trouble on one section will not generally affect the other parts of the system.

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I cannot pass the subject of concrete cell structure without a few words regarding the method of construction. The usual method of building these cell structures is by erecting forms and pouring the concrete, using reinforcing rods where necessary. Owing to the difficulty of securing a uniform and smooth

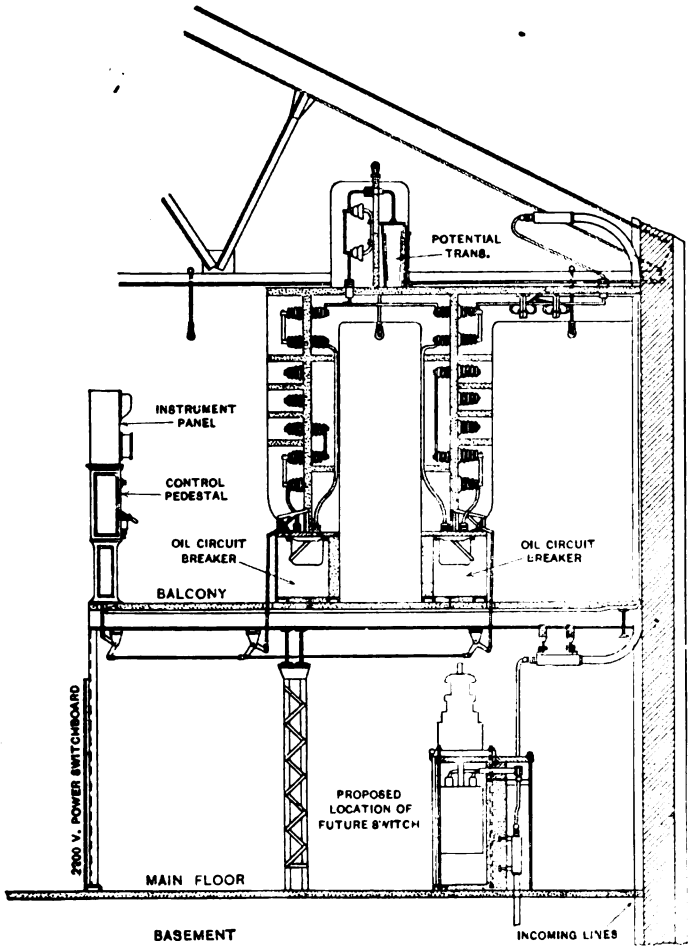


FIG. 13

job, we have digressed a little from the usual method and are building an expanded metal framework and plastering the concrete body onto it. The thickest portions plastered are three inches. The scratch coat contains a small quantity of hair, the remaining coats being pure cement and sand. The finishing

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coat is of Keen cement, which gives a hard, white, smooth surface. In the finishing coat, a small quantity of lime is used to make the cement work more smooth.

Figure 14 gives an idea of the method of constructing the expanded metal framework. Angles are used in the heavy barriers and small channels are riveted or tied to these, the

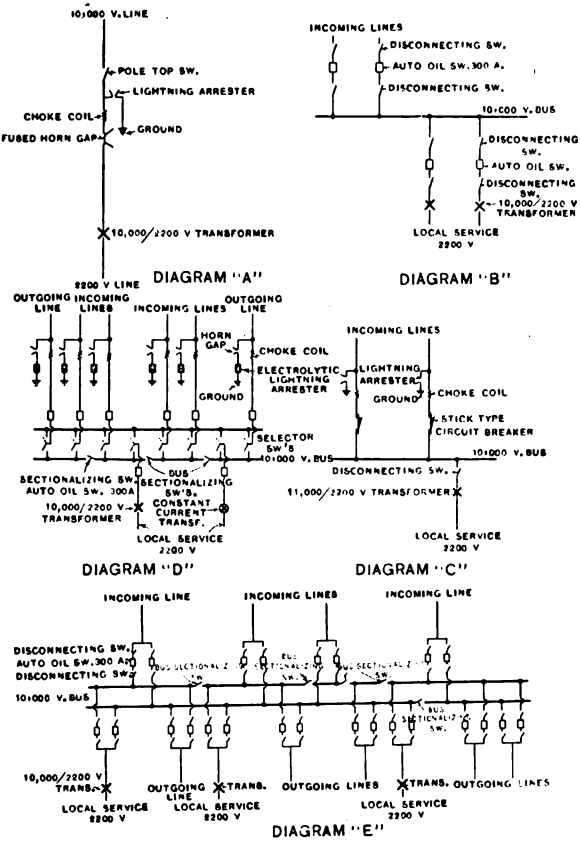


FIG. 15

expanded metal being wired to this skeleton framework. Where the structure is built as in Fig. 11, the reinforcing is keyed in to the main wall.

## COMPARISON OF OUTDOOR AND INDOOR INSTALLATIONS

In company substations, the field for the outdoor installation seems to be with the small towns which can be picked up

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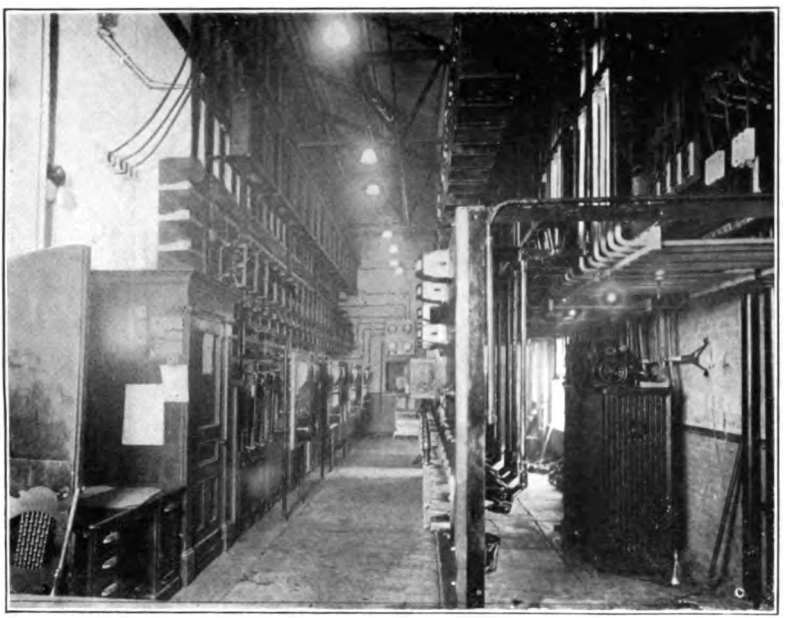

FIG. 11 [FULLERTON]

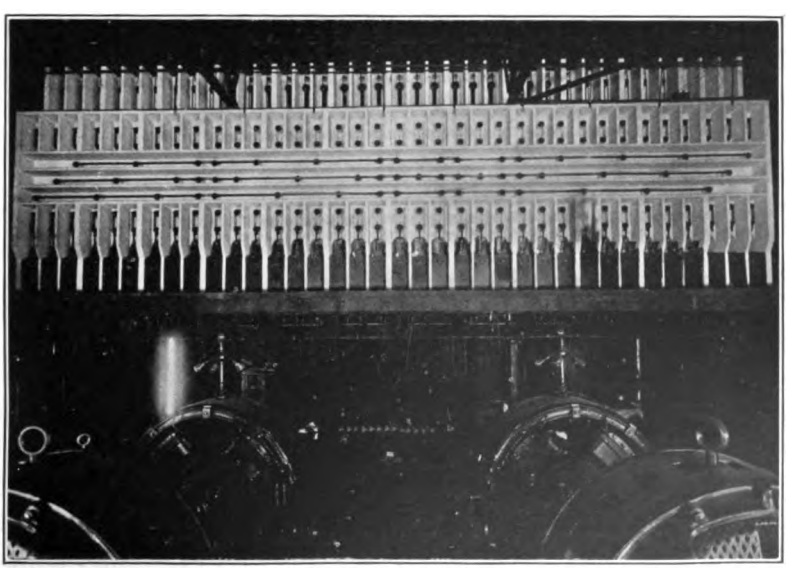

FIG. 12 [FULLERTON]

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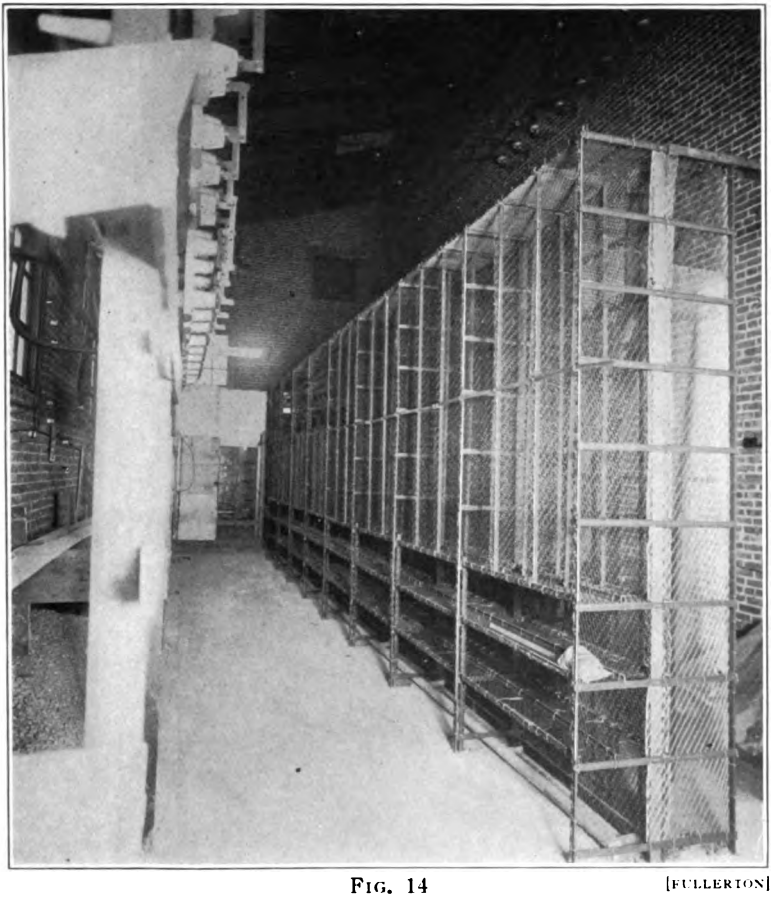

FIG. 14 [FULLERTON]

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along the route of the transmission system without considerable line extension. Where larger municipalities are handled, it is usually desirable to install emergency service which requires more or less high-tension switching, and an indoor substation is usually desirable.

Some of the advantages of an outdoor installation are:

1. Little or no cost for building.
2. Less cost for high-tension apparatus.

Some of the advantages of an indoor installation are:

1. All apparatus protected from weather.
2. Greater ease of inspection and repair.
3. Less depreciation on equipment.
4. Less danger of accident to inquisitive persons.
5. More reliable high-tension apparatus procurable.
6. Safer high-tension construction possible.

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(*Subject to final revision for the Transactions.*)

# OUTDOOR SUBSTATIONS IN NEW ENGLAND

BY FRED L. HUNT

ABSTRACT OF PAPER

The present development of outdoor switching apparatus and transformers for systems of 110,000 volts or less is such as to make their use entirely successful, and in most transformer substations, a considerable saving in first cost can be accomplished without increase in operating expenses, by making use of this type of equipment.

This paper gives a brief description of two substations of 10,000 kv-a. ultimate capacity, just put into operation, in which all the high-tension switching apparatus (66,000 volts) and the transformers are outdoors. The low-tension apparatus (13,200 volts) and the railway apparatus are indoors. This arrangement is based on the three following principles which have in this case proved to be sound:

1. That the greatest saving in building cost can be made by putting all high-tension work outdoors.
2. That the switching apparatus, lightning arresters and transformers of voltages in the neighborhood of 66,000 volts are practical and may be successfully operated outdoors in New England.
3. That distributing switchboard, control switchboard and railway apparatus and switchboard are not suitable for outdoors.

DURING the past summer, there have been built and put into operation by the Amherst Power Company two substations, a brief description of which may be of interest in connection with the present tendency towards the use of outdoor substations. One of these is located at Chicopee and one at Agawam, Mass., both being supplied from the company's double-circuit, 60-cycle, three-phase, 66,000-volt transmission line extending from Turners Falls to Springfield. The accompanying illustrations show various views of these substations, which are practically duplicates as far as general layout is concerned.

When these stations were being laid out, considerable attention was given to a study of the advantages and disadvantages of indoor and outdoor apparatus, the result of which was the adoption of what might be called a semi-outdoor substation in which all the 66,000-volt equipment, including the step-down transformers, was placed outdoors, as were also the aluminum lightning arresters on the 13,200-volt outgoing lines, while the



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13,200-volt buses and switching, the control switchboard, the 2300-volt distributing switchboard and the railway apparatus were placed inside.

The choice between indoor and outdoor apparatus in different parts of the equipment was based on the following considerations:

1. The 66,000-volt apparatus was the most bulky part of the equipment, and therefore the greatest saving in building space could be accomplished by putting it outdoors.

2. The more complicated switching necessary with the numerous 13,200-volt and 2300-volt outgoing circuits and synchronous motor circuits would have been much more difficult and expensive to handle in an outdoor installation. Hence, they were placed inside.

3. The control switchboards, with their motors, instruments and storage battery, and the railway motor-generator sets have not at the present time been developed to the point where it is practical to operate them outdoors; therefore these were placed inside. Except in the case of the switchboards with their meters and instruments, the storage battery and the railway sets, none of which are suited to outdoor operation, the relative location of the remainder of the apparatus, that is, whether it would be placed indoors or outdoors, was determined principally by comparison of estimated first costs, since no well-founded objection to the use of outdoor aluminum lightning arresters, oil switches, transformers or buses could be found.

The saving in the first cost of the building may be arrived at very closely on the basis that the cost of two proposed buildings, erected on the same site, for the same purpose and of the same general design and material, will within reasonable limits, have first cost in the direct proportion to their cubic contents. A building, similar to the one actually erected, but of the dimensions necessary to accommodate indoors all the apparatus, including the 66,000-volt equipment, allowing for the same switching scheme, and providing a space for future expansion equal to that which is incorporated in the present station and outdoor foundations, would cost on the above basis 202/86ths of the cost of the present building. After allowing for the extra cost of outdoor apparatus and the cost of outdoor foundations and steel structures, the saving in this case was an amount equal to 11 per cent of the cost of the complete station and equipment as built.

The general arrangement at the Chicopee substation (see

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FIG. 1—GENERAL VIEW—CHICOPEE SUBSTATION. [HUNT]

FIG. 2—GENERAL VIEW—AGAWAM SUBSTATION. [HUNT]

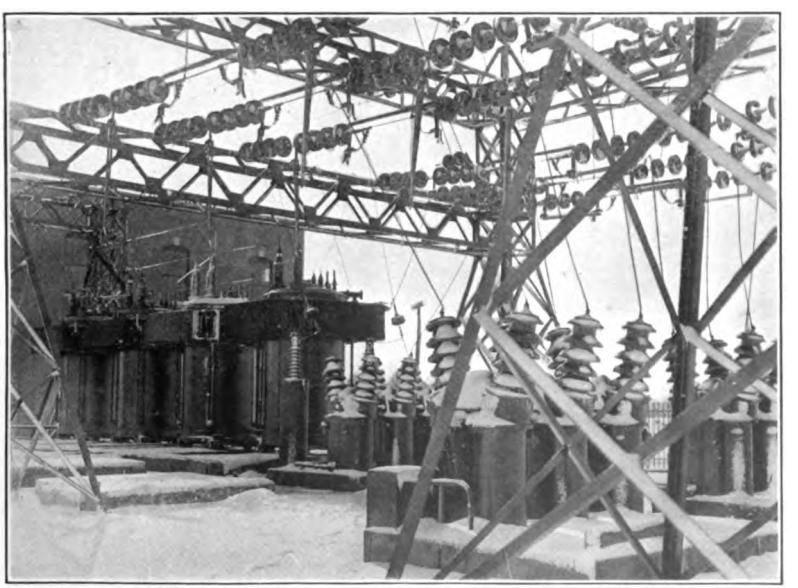

FIG. 3—OUTDOOR APPARATUS, CHICOPEE SUBSTATION. [HUNT]

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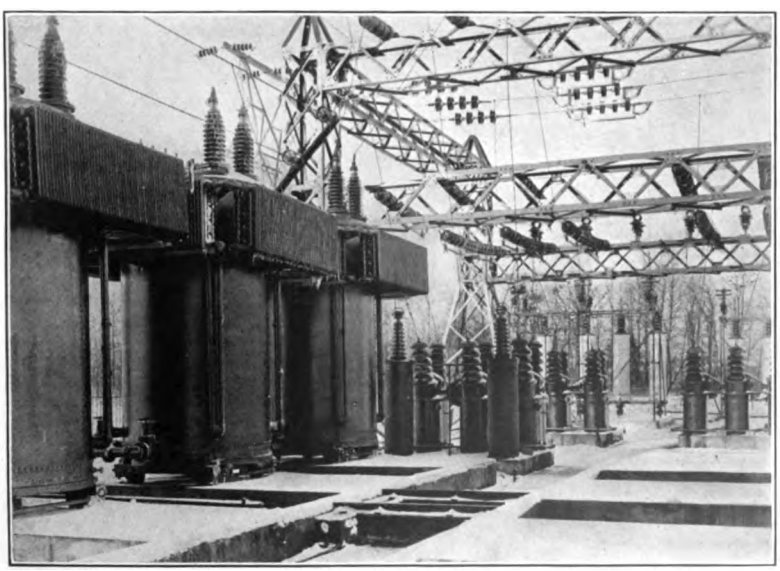
[HUNT]

FIG. 4—OUTDOOR SUBSTATION AT CONSUMER'S PLANT—750-KV-A. TRANSFORMER BANK, 13,200 VOLTS TO 2300 VOLTS.



[HUNT]

FIG. 5—CHICOPEE SUBSTATION AFTER SLEET' STORM.

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Figs. 1 and 3) is as follows: A tap circuit is brought in from each of the two transmission lines through choke coils, disconnecting switches, and solenoid-operated non-automatic oil switches to a transfer bus, from which the transformers are supplied through disconnecting switches and solenoid-operated automatic oil switches, one set for each bank. An aluminum lightning arrester is installed on each incoming line. At present there is one bank of three 1500-kw. oil-cooled transformers of the radiator type in use here, with one spare unit, and foundations and conduits are installed for a second bank. This type of transformer construction brings the cost of oil-cooled transformers for outdoor work down to a point where their increased cost over water-cooled transformers is so little that it does not pay to add the complication of water cooling for the small saving in first cost that can be accomplished, especially where the water would have to be pumped, as in this case, and where, as in all outdoor stations in the northern part of this country, special precaution must be taken to prevent the freezing of water pipes. From the transformer bank one circuit is carried underground into the building to the 13,200-volt double bus in a concrete bus structure.

The arrangement so far as outdoor station is concerned, is the same at Agawam (see Fig. 2) except that there is a difference in the capacity of transformers, and there are two circuits from the secondary side of the transformers into the building; one leading to the 13,200-volt bus, and one to the 2300-volt bus, as power is distributed at both voltages from Agawam station.

Attention may now be called to some special features of the outdoor equipment. The oil in the outdoor transformers freezes at −15 deg. cent. It is therefore necessary to keep the temperature of the oil in the spare transformer above this point if it is to be ready for immediate service. This will be accomplished by connecting the spare transformer to the bus on the low tension side, from about Jan. 1st to Mar. 10th of each year. During the remainder of the year the temperature of the oil in the spare transformer does not go down to its freezing point when left without artificial heat.

The transformers and oil switches are connected by a complete piping system to a two-compartment oil tank buried in the ground, so that oil can be drained from any transformer or oil switch into its respective compartment of the oil tank,

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and from there can be pumped through a portable oil filter press back into the transformers or switches. Alarm thermometers on the transformers are connected to bells in the station. There is installed in the cover of each transformer a small heating unit taking 200 watts at 110 volts. The object of this unit is to keep the air in the top of the transformer, and especially the spare transformer when not excited, a little above the temperature of the air outside, so that in the process of breathing, which is sure to be present to some extent in any large transformer subjected to varying temperatures, the air taken in, even though heavily laden with moisture, will have that moisture vaporized by coming in contact with the warmer air inside, rather than being further condensed by coming in contact with cooler air inside, which latter condition would occur if there was no artificial heat inside the cover of the transformer.

When it becomes necessary to disassemble a transformer it is rolled on to a transfer truck upon which it is run into a compartment at one end of the station where a hoist is available of sufficient capacity to lift and remove the core. Switch hooks used for operating the disconnecting switches outdoors are fitted with a copper cone at about the middle of the handle, which cone is grounded when the hook is to be used. All the outdoor aluminum lightning arrester cans are painted white to overcome a difficulty experienced in warm climates where the absorption of the sun's heat by dark-colored cans has raised the temperature of the electrolyte of the arrester to a point where it was damaged. Two coats of white paint on these cans have been sufficient to keep the temperature of the arresters below the danger point in these installations, up to the present time. This same treatment may be applied with similar results to the transformers where excessive temperatures are reached on account of the sun's direct rays.

The winter weather test of these substations has already begun and the results so far observed are satisfactory. The Chicopee station after a recent sleet storm is illustrated in Fig. 5.

Each outdoor station is surrounded by an iron picket fence and all the equipment is set on concrete foundations extending below frost line and about 15 in. (38.1 cm.) above the final level of the ground. Thus far in the operation of these stations nothing has occurred which indicates any important point of disadvantage in the outdoor arrangement, except that some difficulty was at first experienced in keeping the joints of the

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cooling radiators on the transformers oil-tight, due to the wide range in temperature to which they were subjected every 24 hours. The design of these radiators has now been changed, and the new radiators have thus far stood the test of wide temperature changes without developing leaks.

It is probable that in practically all substations of the same general arrangement as these, considerable saving can be accomplished by the outdoor arrangement of the high-tension apparatus, except where cost of land is very high as in cities. There is no reason why with proper local conditions, a considerable saving cannot be accomplished by the use of out door apparatus at generating stations. In other cases, the saving may be small or none when the particular arrangement of canal intakes and generator rooms is such that only a small additional expense is required to house the transformers and high-tension switching. Each case should receive special consideration. There appears to be no good reason for using outdoor apparatus except where a saving in first cost can be shown.

Outdoor apparatus is also used on this system at several of the consumers' substations, where power is delivered at 13,200 volts and stepped down to 2300, 550, 440 or other voltages. Fig. 4 is a view of a typical station of this kind where power is delivered at 13,200 volts to a bank of three 250-kv-a. oil-cooled, single-phase transformers, and stepped down to 2300 volts for use in a textile mill.

The transformers are connected to the 13,200-volt circuit through combination horn-gap arresters and choke coils, and horn-gap disconnecting switches, and the power is metered at 13,200 volts by the use of outdoor potential transformers, indoor current transformers under shelter, and a meter in a box with glass cover. The tower stands approximately 20 ft. (6 m.) high, the bottom of the transformers being about 10 ft. (3 m.) from the ground.

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*To be presented at the 2d Midwinter Convention of the American Institute of Electrical Engineers, New York, February 25, 1914, under the auspices of the Electric Power Committee.*

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# OUTDOOR SUBSTATIONS IN THE MIDDLE WEST

BY LESLIE L. PERRY

ABSTRACT OF PAPER

Conditions in the Middle West, particularly in the agricultural districts, have often been such as to necessitate the construction of small 33,000-volt outdoor substations in order to make the supply of current commercially practicable.

These stations have been constructed with very simple switching and protective equipment and economy of design and protection to the main line have been the dominating feature of design.

Operation of such stations has been successful and they are of great benefit to the communities served.

Improvement in lighting and overload protection is looked for.

THE CONDITIONS in such states of the Middle West as Illinois, Indiana, and Kentucky, are very favorable to the use of small outdoor substations. Many of these have been built during the last year, and more undoubtedly be built in the next few years. There is little very high-tension transmission within 300 miles (482.8 km.) of Chicago, but there is a large amount of 22,000-volt, 33,000-volt, and some 50,000-volt transmission. These lines for the most part serve districts that are not densely populated. In many sections, particularly in Illinois, the communities are almost purely agricultural, with only those small industries associated directly with agriculture.

In the manufacturing States, particularly in New England, oftentimes a factory or mill can readily supply electricity made either by water power or steam on a moderate investment cost and with a very low operating expense. But many of the richest agricultural districts of the Middle West are without small reliable water powers, and cheap, economical steam plants are impossible under the conditions.

Many towns of 2000 people have three-fourths of their people within a radius of a mile (1.6 km), and the entire electrical business of one of these towns may not warrant the expense of more than a single man devoting his entire attention to electric service. Where, as occasionally, local plants have



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been built, they usually have rendered very indifferent service, and seldom operate throughout the 24 hours. With a distribution system of 33,000 volts near-by, of course continuous service can be readily given; but in order to make such service commercially possible, investment and operating costs must be kept within the lowest reasonable limits.

It frequently happens that such local plants as exist have not enough floor space or head-room to house 33,000-volt apparatus, and in other cases there are no suitable buildings, so that immediately there comes up the question of building investment.

In the climate of Chicago, it is the opinion of many engineers that somewhat more reliable operation will be had with indoor apparatus, and where housing has to be provided for considerable apparatus, such as street lighting equipment, feeder-regulators, and perhaps a motor-generator or a synchronous converter, the size of the load and the number of customers served warrants a new building. Of course, with voltages of 60,000 and above, the indoor station would not be possible where it can be used at 33,000. Where the load is below 300 kw. it is often considered that on voltages of 33,000 and above, the cost of any high-tension oil switch and aluminum cell arrester is not warranted, so that very simple outdoor high-tension switching and protective gear with the outdoor type transformers make a substation equipment well adapted to the requirements. Where no indoor space is available, just enough housing is provided to protect a low-tension oil switch, a watt-hour-meter, ammeter, and voltmeter, with space for a street lighting regulator if required.

While many stations have supporting frames built of wood, undoubtedly more and more of them will be built of steel. At first thought one would consider the wood much cheaper; but taking into account that the steel structure can be built by efficient shop labor with minimum erecting costs, while the wood structure requires the less efficient field labor, and does not have the reliability, life, or freedom from fire risk that the steel does, it will be found the wood structure is not any cheaper.

A station to handle three 50-kw. transformers can be supported on a tower with a six-foot (1.8-m.) base as shown in Fig. 1. A six-foot square house of galvanized iron or heavy sheet steel is ample for most requirements and accommodates a 2300-volt low-tension panel as shown in Fig. 2, and incandescent outfit for street lighting.

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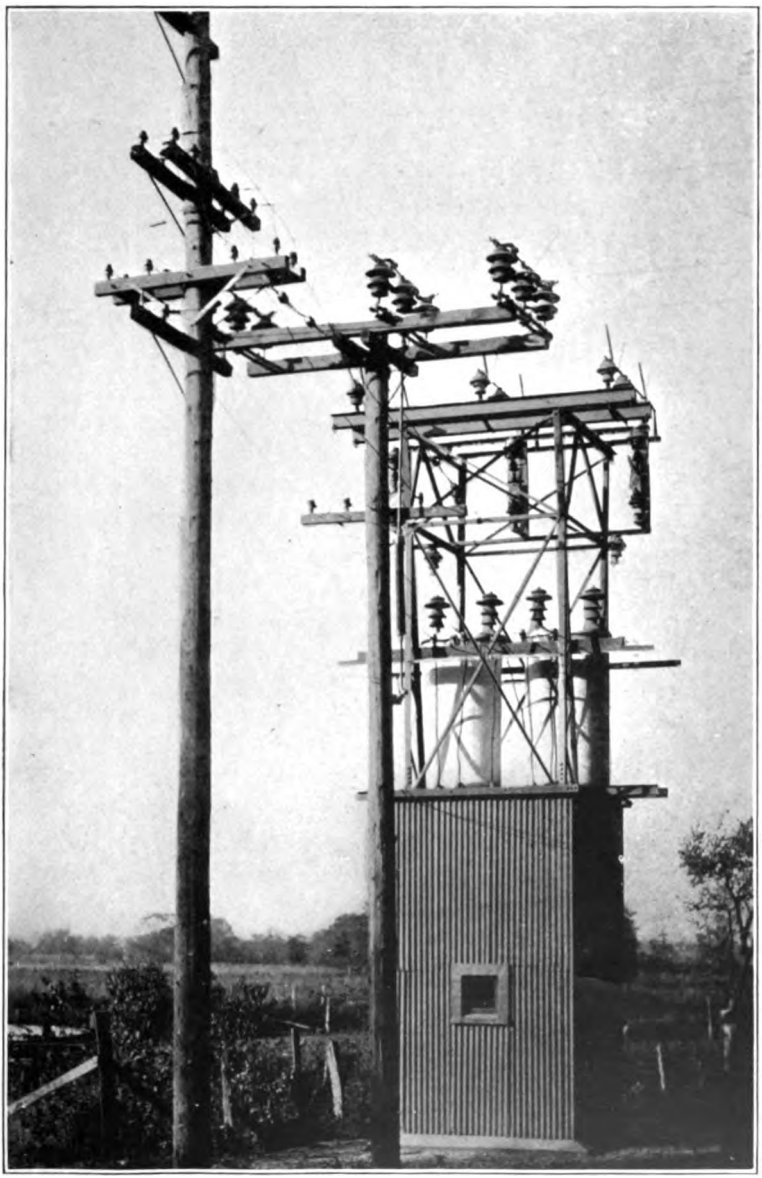

[PERRY]

FIG. 1—33,000-VOLT OUTDOOR SUBSTATION EQUIPPED WITH TWO 50-KW. TRANSFORMERS AND SPACE FOR THIRD.

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[PERRY]

FIG. 2—LOW-TENSION PANEL USED WITH OUTDOOR SUBSTATIONS.

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These substations are connected to transmission lines supplying substations of larger size, say 600 kw. per station and above; provision should therefore be made to automatically cut free these outdoor substations from the transmission lines in case trouble develops in the small station. Hence, in the supply of power to the small rural station, the chief requisites to be met are: 1, economy of design, 2, protection to the main line, and 3, reliability of service in so far as the elements of the outdoor station itself are concerned.

Up to the present these stations have been very successful. The problems of overload and lightning protection have been solved with reasonable success, but unquestionably improvement can be made in these directions. In the absence of better devices of reasonable cost, either the plain wire fuse on horn gaps, or the liquid high-tension fuse with or without horn gaps, have been chiefly used for protecting the line, reliance being placed on the low-tension devices for overload on the substation itself.

For lightning protection a ground gap has been used, and the substation fuse is so mounted as to protect the line when the line current too freely follows the lightning. Choke coils are used in the transformer leads.

In designing such stations it should be remembered that they will often be in the hands of inexperienced operators, and hence every precaution should be taken to permit proper attention by ordinary emergency men; for this reason many stations have been built with disconnecting switches on a separate pole with lever gear such that the switch can be operated by any intelligent man. With this arrangement fuses can be replaced or defective transformers exchanged on a structure absolutely without any live wires connected to it.

In mounting the transformers well above ground, due regard has been paid to keeping the high-tension apparatus as free as possible from interference from careless or inquisitive boys, marauding animals, or the washer-woman's wind-blown laundry.

Sufficient success has been attained to demonstrate that by using these small outdoor stations good electric service can be supplied rural communities at attractive prices, and the central stations and the manufacturers are rendering true public service in reaching communities otherwise unable to benefit by central station service.

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# PROBLEMS OF HIGH-TENSION TRANSMISSION LINES

REPORT OF SUB-COMMITTEE ON TRANSMISSION

P. W. SOTHMAN, CHAIRMAN

## INTRODUCTORY

IT IS not intended that the following article shall completely cover the very broad subject of transmission of electrical energy, but only outline some of the more important problems which have to be considered when building and operating high-voltage lines. Such data as are contained herein have been supplied by the members of the sub-committee with the idea of furnishing a basis for discussion, for it is recognized that the principal value of a paper of this kind lies in the discussion which it may elicit.

Some of the topics of particular interest at this time have been treated in short special articles which are published as appendices to this report and which appear under the names of their respective writers.

## RIGHT-OF-WAY

In sparsely settled countries there is generally no trouble in securing as much land as may be needed for the erection of the transmission and telephone lines, and the only point to bear in mind is the choice of route involving the least constructional difficulties, such as the crossing of mountain ranges and streams or the avoiding of locations which make patrolling and maintenance unduly expensive. If a restricted locality were known to be particularly subject to lightning storms, this would naturally be avoided, if possible.

On the other hand, in districts like the East where the land is already fully occupied and sometimes quite valuable, the right-of-way problem is often not an easy one, and the question arises as to whether it may not be advisable to obtain easements, giving the company the right to erect and maintain its lines across the lands of the owners. Tower lines may even cross fields under cultivation, causing practically no inconvenience to the farmers, who have been known in many cases even to plow and grow grain between the legs of the towers themselves. For



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convenience in patrolling and the making of repairs, the route should, as far as possible, be chosen alongside of highways, regardless of whether the right-of-way is purchased outright or not. The width of right-of-way is an important consideration, as well as the minimum clearances which should be allowed above ground.

There are cases in which it may sometimes be advisable to utilize the right-of-way of an existing steam or electric railway, provided a suitable agreement can be reached between the respective parties. This arrangement has been objected to at different times by laymen because of the alleged danger to the traveling public. That this objection is groundless, we all know, and decisions have been rendered by at least one State Public Service Commission to this effect. Objection to this practise has also been made by the telegraph companies occupying the same rights-of-way, on account of the interference which may be set up in such circuits because of the proximity of the power lines. By the use of proper care these troubles may be reduced so as to become unimportant, so that this objection also is overcome.

Under this heading may also be included the constructions necessary for the crossings of railways and other circuits. There is at present no generally recognized type of crossing protection, and whatever kinds are used are usually subjects for agreement between the parties concerned. Certain protection from falling wires or cables is desirable, but we feel that the matter has been carried to extremes in many instances. If two power companies adopt elaborate and expensive means for protecting their respective circuits where crossing one another, when an ordinarily substantial construction of the lines themselves would suffice, how can they object if the telephone and telegraph companies, whose lines they have to cross, insist that an equally elaborate protection be installed for their crossings also? This shows the need for an intelligent agreement upon the subject and for a code of rules or specifications, preferably bearing the sanction of the Institute, which will be accepted by all parties. Such specifications should allow a certain latitude in the construction so as not to inflict unnecessary hardships upon small power companies operating at comparatively low voltages, or those located in unsettled districts.

## Towers

The selection of the type of tower depends upon the number of circuits to be carried, line voltage, whether suspension or

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pin type insulators will be used, the physical characteristics of the country through which the line will pass, and also upon the climate. It is generally agreed that the square or four-legged tower is more efficient in the use of material than the three-legged tower and the latter is seldom seen nowadays in new work. The flexible type of tower has also been used to some extent with good results, but it is necessary to place rigid towers at frequent intervals along the line to act as stays, from which the flexible towers are more or less supported by the overhead ground wires and also by the power cables when pin insulators are employed. It is too early to say what success will attend the flexible tower when used in connection with long suspension insulator strings, and until more data are available upon the subject it is advisable to proceed with caution when considering the adoption of this construction.

Where suspension insulators are employed, it has been found that it is not good practise to place two or more conductors in a vertical plane, especially where snow and ice are liable to collect upon the cables. When this load breaks away it very seldom does so uniformly and the cables are in great danger of coming into contact. This phenomenon has been quite fully treated in a recent paper. It might be added that it has been observed in the East that ice seems to collect to a greater extent at the centres of the spans than near the towers, which should be taken into consideration.

The method of calculation of tower designs should be standardized, and the constants for such materials as copper, aluminum and steel used for conductors should be taken at some acceptable figure such as 30,000 lb. for copper, and 14,000 lb. for aluminum, as representing the elastic limit of the material. The design should be calculated so that when the loads estimated are all on the structure will be stressed to the elastic limit. The factor of safety is therefore in assuming excess loads over those which are known to be liable to happen.

Ordinarily towers should not be calculated, but they should be specified to stand certain loadings, and should be tested for these figures.

*Foundations.* It is very important in the use of rigid towers to see that the foundations on which the tower stands are all at the same height, and therefore, it should be specified that the foundations of the tower should have their tops within 1/10 of an inch of the same height.

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*Minimum Thickness of Material.* In the construction of towers no material should be used less than 3/16 in. (4.7 mm.) in thickness.

*Bolted Connections.* It is recommended that the minimum number of bolts in any connection be not less than two.

*Strength of Members.* It should be kept in mind in the design of the towers that men are likely to climb up and down the towers on the angles, and therefore, one of the limiting conditions is to see that no members are used which would be bent by the weight of a man in so climbing a tower.

*Movement of Wires.* It would seem advisable to increase the customary figure of 45 deg. used for angle of deflection of the insulators to 55 deg. or 60 deg. from vertical, under the worst wind conditions.

The effect of ice and sleet should be considered, and this from the point of view of non-uniform loading. The structure should be so designed as to permit the loading of one span with the two adjacent spans not loaded, and still have sufficient clearance between all the wires so that under these conditions there would not be probable contact due to wind conditions.

*Amount of Sleet.* Not less than $\frac{3}{4}$ in. (19 mm.) of sleet or ice for the northeastern part of the United States and the eastern part of Canada should be allowed for.

*Wind Load.* The wind load is heaviest at times of sleet, and it should be recognized that the sleet does not form uniformly around the wires, but that the section of the ice is more or less elliptical.

*Wind Pressure.* It would seem advisable to increase the amount of wind pressure for the eastern part of Canada and the United States to about 15 lb. (6.8 kg.) pressure per sq. ft. (0.09 sq. m.) on the round surface.

The usual method of erecting towers is to assemble them lying on the ground and then tilt them into place, which is apt to induce faults in them, hence it is very necessary that a careful inspection be made of them after erection, with a view to tightening up the bolts and examining the various members to see whether they are distorted.

In many cases towers have been provided with insufficient means for supporting and firmly holding the ground cables. The ground cable clamps should be quite long and have not less than four bolts so that the cables cannot possibly slip, allowing them to sag down in contact with the power conductors.

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*Galvanizing and Painting.* From reports received from various quarters it appears that the galvanizing of steel towers is generally preferred to painting. Probably the manufacturers themselves differ more on this point than the users of towers. One manufacturer advocates painting because of the simplicity obtained in erection by having the sides of the towers assembled complete and riveted in the shops, only the cross members requiring to be bolted together in the field. Large pieces assembled in this manner cannot well be galvanized and painting must be resorted to.

Paint affords a good protection if the structures are periodically gone over and carefully scraped and cleaned before the paint is applied. It is very difficult, however, to reach all small interstices and pockets and these are the places where rust is most apt to occur. Superficial inspection frequently will not disclose rusting which may be occurring beneath the paint coating. There is no doubt that periodical repainting is more neglected than otherwise.

Galvanizing, on the other hand, practically eliminates worry and expense for maintenance, as it is electro-positive to iron. The galvanized coating has two functions to perform. In the first place, it is designed to keep the surface of the steel from coming into contact with water and the atmosphere, and secondly it protects the iron whenever water and oxygen finally succeed in breaking through.

If the galvanizing is properly done, it may be relied upon to be in good condition at the expiration of 12 or 15 years, whereas painting cannot be depended upon much longer than two or three years, especially where the atmosphere contains sulphur or other fumes.

Footings extending into the earth may be galvanized with good success in most soils, although there are earths where asphaltum paint coating is more durable. In cases where extreme acidity or electrolytic action is expected in the soil, it is more economical in the long run to provide a concrete footing thoroughly encasing the steel.

## Conductors

The relative merits of copper and aluminum conductors have been discussed quite often and it is not our intention to open the subject again at this time. A thorough understanding of the different qualities of the two metals should be had by engineers designing transmission lines, especially where suspension

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type insulators are considered, in order that advantage can be taken of these qualities. There are certainly places where aluminum should not be used as power conductors, but on the other hand, there are quite often cases where it might be used to better advantage than copper.

Experience has shown that hard-drawn copper cables should not have hemp centers, for an action partly chemical and partly mechanical is set up which sooner or later weakens the strands and causes the cable to part.

In order to secure a greater strength and also partly to add weight to the cable a steel core has been inserted in some of the aluminum cables recently manufactured. While it is claimed by the makers that such cables are as durable as the ordinary aluminum cables and free from electrolytic corrosion, conclusive proof upon this is still lacking. It is understood that steel cores in aluminum cables are not considered satisfactory by English cable manufacturers.

For long spans where great strength is required, wires and cables made of steel having a coating of copper (copper-clad steel) are available, which give very good results. These wires are still too high in cost to be used generally for power conductors. They are coming into use to a certain extent, however, for telephone and telegraph lines.

In passing, it may not be out of the way to remark that there are several formulas in existence, all more or less tedious in their application, for the calculation of cable sags, taking into account temperature changes as well as spans and tensions. The majority of these are adaptations of the parabola formula and will give sufficiently accurate results so long as the spans and sags are moderate. We would suggest that some simple method, such as a set of curves, be evolved, based preferably on the catenary, from which the sags may be quickly and accurately determined for all possible conditions.

*Ground Wires.* It is generally agreed that overhead ground wires are beneficial as a protection against lightning. Just how much protection is actually afforded, however, is still a mooted point. A report given below, on this subject from one of the large companies in the West well illustrates the feelings of a majority of operating engineers.

This company has about 450 miles (724 km.) of 60,000-volt pole line without overhead ground wires, and about 100 miles (160 km.) with the overhead ground wire.

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In the case of one particular branch about 42 miles (67.5 km.) long, running northerly, we feel that we have had reliable and conclusive evidence that the overhead ground wire does protect. We have had a number of thunder storms cross this line at right angles, and while lightning would sometimes cause the automatic oil switches to open at the power station, yet no real damage occurred to either the line conductor or insulators, neither were the poles split by the lightning discharges. In other words, service could be re-established at once. On the other hand, these same storms would sometimes destroy pin type insulators and pole tops, on lines not protected with the overhead ground wire, and the general opinion has therefore been formed that the overhead ground wire does protect against material of the line being destroyed. However, we do not have either the number or severity of lightning storms that a large portion of the states do. We have, on all new work permitting the expense, equipped our lines with the overhead ground wires.

We might add, however, that the testimony is not altogether in one direction. While we have had very good direct evidence of the usefulness of the ground wire in one line, on another line we have had several insulators shattered, notwithstanding two ground wires on the top of a steel tower transmission line. These troubles, however, have been due to what we are quite sure have been direct strokes of lightning.

## INSULATORS

Reports received from various parts of the country indicate that the suspension insulator as usually manufactured, in the disk type with metal caps and pin, is quite satisfactory when new, accomplishing the purpose for which it is intended, up to voltages of at least 150,000. The fly in the ointment, however, is that after they have been a year or two in service, failures begin to occur, and as time goes on a large number of the sections have to be replaced. To insure steady service on the lines the insulators have to be inspected at frequent intervals to weed out any that have become faulty. This trouble is not confined to any make of insulator nor to any section of the country. Extracts from reports from several companies are given herewith which will serve to show how prevalent the difficulty is and the means employed for inspection. The first report deals with conditions encountered on the lines of two or three companies in the South.

The Carolinas experienced very severe lightning during the past summer. Following repeated failures of insulators in a limited portion of a certain line, under the writer's observation, it was believed that there might exist insulators which were punctured, but of which no external signs were visible.

The line in question consisted of a single and double circuit steel tower line, equipped with suspension insulators and one ground wire.

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It was accordingly determined to see if it was possible to locate any such punctured insulators by means of a megger.

A megger was secured, giving 500 volts, and reading 1000 megohms. The method of procedure was as follows:

On a single-circuit tower line a party was organized consisting of engineer in charge of megger, and six linemen, working in pairs. One pair would proceed to ground the line on a certain tower and hold the leads of the megger, which consist of about 100 ft. (30.4 m.) of standard lamp cord, to the individual disks in the strings of insulators, by means of two wood handles. The readings would then be taken, whereupon the megger would be taken to the next tower on which another pair of men were ready to go through the same procedure. With this arrangement about four towers per hour could be tested, each tower being provided with eighteen disks.

On a double-circuit line about 26 towers were covered in ten hours.

The following results were obtained:

On a total of 2100 disks under observation, 14 of this number were found defective.

Twelve disks had defects invisible from the ground, and in two disks the defects were visible from the ground.

Of the twelve invisible from the ground, two of these could be noted as defective from the tower, four could be detected by very close inspection, after taking down, and six showed absolutely no defect.

One of these disks, the defect of which was entirely invisible, measured 300 megohms, two measured 250 megohms, and the balance were less than five megohms, which was the lowest point on the scale. Good disks were considerably over 1000 megohms.

*Insulator failures with reference to their location on line, and relation to ground wire:*

On a 100-kv. line, protected by ground wire, of a total of 94 failures of disks, it was noted that 28 were on the top wire, 25 on the middle wire, and 40 on the bottom wire.

*Insulator failures in reference to steel towers vs. wood poles:*

Insulator failures were compared on the following basis:

100-kv. tower line..... 35,770 disks
Failures..... 94 "
(Wires arranged vertically, single and double circuit, one ground wire)
60-kv. tower lines..... 2440 disks
Failures..... 4 "
(Wires arranged horizontally, single circuit, one ground wire)
60-kv. wood pole line..... 14,850 disks
Failures..... 4 "
(Wires arranged on right triangle ,single circuit, one ground wire)
60-kv. wood pole line, using pin type insulators. 5718 insulators
Failures..... 1 insulator
(Wires arranged in right triangle, single circuit, no ground wire.)

The suspension disks are 10-in. (25.4 cm.) corrugated, single piece porcelain. The pin types are four-part, 14 in. (35.5 cm.) diameter, 12½ in. (31.9 cm.) high.

In connection with these failures it should be noted that the 100-kv.

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line is equipped with six disks per string and the operating voltage is between 95 and 100 kv. The 60-kv. lines have three disks per string and operate from 60 to 65 kv. The pin type insulators operate at 60 to 62 kv.

Probably one-third of the failures on the 100-kv. line occurred when the line was dead and the two ends of the same grounded. Of the four failures on the 60-kv. wood pole line, using suspension insulators, three of these occurred while the line was temporarily operating at 22,000 volts. The pin insulator failure occurred while the line was dead and all three wires grounded at one end. The question arises after considering these failures whether there is any use in having more disks than is required to give a reasonable factor of safety on insulators and also whether wood crossarms on steel towers should not be seriously considered.

Next follows a report from a California company.

Regarding the experience of the Southern California Edison Company with high-tension transmission lines, this company built a transmission line of 70,000 volts and about 120 miles (193 km.) long.

The towers are of steel, and a pin type insulator was used, being 18 in. (45.6 cm.) in diameter. These insulators were carefully tested out in the factories in the East, and were of three different makes.

These insulators gave absolutely no trouble for a period of at least one year, and the only line trouble experienced was due to eagles grounding the wire to the steel towers. However, after the second year had passed we began to experience considerable puncturing of insulators, and a careful inspection disclosed many insulators which were honeycombed with minute cracks. The line was very carefully gone over, each insulator being struck with a piece of hickory wood; this being the method used in testing fine porcelain ware in the china shops. All defective insulators were carefully culled, every one not ringing true being at once removed. We sometimes found indications of cracks on the rim of the insulator, but as a rule on one or the other of the petticoats. During the past five years, I have brought this matter energetically to the attention of the porcelain manufacturers, and have always insisted that the porcelain of the insulator shows an apparent aging, the cause of which we have been unable as yet to determine. This may be due to the extreme changes of temperature, to the continual vibrations of the wire, or perhaps a combination of the two; at any rate the aging of these insulators is going on with increasing rapidity, and every inspection of the line means the finding of hundreds of defective insulators which were in good shape the year previous.

In changing these insulators over (which work is going on at present) all are being replaced, both good and bad, with the suspension type. We have endeavored to use a few of these large 18-in. (45.6 cm.) insulators on some of our local 33,000-volt lines, with the idea that they would be serviceable in sections where the salt from the sea rapidly encrusts them; but even at this low potential we have had many of them break down electrically, showing that the insulators which originally stood the test for 100,000 volts were rapidly becoming wholly unfit for any of the high-potential work.

Our experience with the suspension type insulator has been too limited

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to warrant us in giving an opinion as to their superiority over the pin type, but on our 60,000-volt line, four insulators in series, extending from Long Beach to Colton, a distance of approximately 80 miles (128.7 km.), we have discovered a great many broken insulators; especially when used as strain insulators. These were evidently broken by extra mechanical strain, and showed no exterior indication of injury. We, however, are watching this very closely, and have gone to the expense of changing the sets of insulators, taking the old ones back to our laboratory for test. As stated above, there appears to be a continual aging of all porcelain insulators going on, and they seem to be short-lived. Whether this is due to the combination of electrical and mechanical strain, I am unable as yet to say.

The following report by another engineer is along the same lines.

Experiments in the method of eliminating defective insulator sections by tests of insulation resistance with a megger have been conducted on the 100-kv. lines of the Yadkin River Power Company in North Carolina and upon new insulators in Utah intended for erection on the 130-kv. lines of the Utah Power & Light Company.

The Yadkin River Power Company operates 96 miles (154.4 km.) of double-circuit 100-kv. line from the Blewett Falls generating station to Raleigh and connecting through to the Southern Power Company at Durham, and also a 56-mile (90.1 km.) single-circuit line from Blewett Falls to Lumberton. This latter line is supported in part by single-circuit towers and in part by double-circuit towers carrying also a 22-kv. circuit. The conductor is three-strand No. 1 B. & S. copper. There is one overhead grounded cable and the insulators consist of six 10-in. (25.4 cm.) disks of the usual type. This line traverses a district subject to lightning storms of unusual and even extraordinary severity. During the past summer, the first lightning season of the line's service, there have been numerous cases of insulator trouble. Nearly all of the trouble has been experienced over a short section of about six miles (9.6 km.) length. The section is in open country and contains no angles or special features of construction, and no explanation of its especial susceptibility is obvious except that the storms appear to be of greatest severity in this vicinity. Failures have occurred usually on insulators supporting the top or the bottom conductor. The top conductor changes to the bottom at a transposition point in this trouble section.

The failures have been almost all of the same character; a disk will be punctured through the head, inside of the cap, the puncturing will be accompanied by an explosion which will blow considerable porcelain from the cap, causing the disk to separate and allowing the line to drop. The disk usually affected is the lowest of the string.

The load at Lumberton is mainly cotton mill power and no power is taken on Saturday afternoon and Sunday. On Saturday and Sunday, August 16 and 17, megger tests were made of all of the disks on 28 towers, covering between three and four miles of the section which has been experiencing trouble.

On the 28 towers were 94 strings of six disks each, or 564 disks. The disks were tested one at a time. Thirteen disks or 2.3 per cent were

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found to be defective, the 13 disks occurring in 12 strings. Of the 13 punctured disks, two would have been apparent from the ground, since the disks were broken; six could have been discovered by close inspection after climbing the tower, since there were cracks in the metal insulator cap; three could not have been observed from the tower but would be apparent after taking down the insulator; and in two cases the disks did not show any visible evidence of having been punctured, although the megger showed them to have no insulation value.

Although these tests were on a very small scale and there has been no subsequent opportunity for continuation of them, yet they indicate that frequently a string of insulators will fail gradually, one disk at a time, and that a considerable measure of protection may be secured by periodic elimination tests with a megger, provided lines may be taken from service for the tests.

In Utah experimental tests have just been started on insulators not yet erected. The first reported test was as follows:

A. 400 10-in. (25.4-cm.) disks were tested and found good.

B. 100 10-in. (25.4-cm.) disks of another make were tested and found good.

C. 264 pillar insulators each consisting of three 10-in. (25.4 cm.) disks were tested; 26 insulators contained one bad disk each and two contained two bad disks each, a total of 12 per cent bad insulators or 4 per cent bad disks.

The insulation resistance of the defective disks ranged from 550 megohms to a value below the scale of the megger, which was one megohm.

D. 12 pillar insulators of another make, each consisting of eight 14-in. (35.5-cm.) disks, were tested and one disk found bad. The insulation resistance of this disk was about 25 megohms.

The defective insulators had been subjected to a factory high-potential test before shipment.

Three of the low-resistance 10-in. (25.4-cm.) disks in the pillar insulators mentioned above were subjected to a high-potential test and all failed, although at such voltage values as to make it seem possible that some would have stood up for a considerable period in service before actually puncturing. In the case of two others of the low-resistance disks, the metal caps were drilled off, but no cracks or visible defects were found. In general, it seems probable that clean insulators which have the low values of insulation resistance noted above will not stand high-potential service, owing to the local heating which would inevitably result.

These Utah tests are being continued with a view to determining the advisability of making such tests of all of the insulators on hand before putting them into service.

It is planned to incorporate a megger test in the specifications for all future insulator orders.

At voltages around 110,000 and even somewhat higher, there seems to be no reason for providing protection for the end units of suspension insulator strings to equalize the voltage gradients over the whole. There will doubtless come a time, with higher

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voltages, when such protection will be needed, and experiments have been made which demonstrate the efficiency of end shields for this purpose. These shields act simply as electrodes for equalizing the electrostatic field in the region occupied by the insulators. Shields should present smoothly rounded surfaces and edges and need be no greater than 12 to 14 in. (30.4 to 35.4 cm.) in diameter to produce good results. With these shields may be mounted arcing rings or tips to keep arcs away from the insulators as found necessary.

### Clamps and Fittings

There are several types of clamps on the market intended to secure the line conductors to suspension and strain type insulators. These all perform this function very well insofar as they do not allow the conductor to slip. Some are so severe, however, that the cable is mashed and unfit for taking strains if the sags ever have to be readjusted, by no means an uncommon occurrence. Practically none of the clamps are designed with smooth outlines or with an idea of avoiding more or less sharp projections which cause static discharges at the higher voltages and which concentrate the electrostatic field in that vicinity.

### Notes on Station Apparatus

Rapid improvement has been made in the design and construction of transformers since the advent of the higher voltages. It was a comparatively simple matter to build a transformer for 60,000 volts which would stand up under all manner of severe service without ever giving any trouble, even when used with a large generating capacity back of it. Transformers built along the same general lines with more insulation were then tried at 110,000 volts, but trouble developed almost at once, sometimes through the short-circuiting between turns of the windings or else at tap points, and quite often by the distortion of the coils under short-circuit conditions. It was then recognized that because of their different physical constants, the higher voltage transformers were, so to speak, much more susceptible to line disturbances such as switching, etc., than those for lower voltage, and the designs have been changed accordingly, much attention being given especially to the bracing of the coils. The greatly improved results which have been obtained since these changes have been carried out, testify to the soundness of the principle of strengthening apparatus against failure rather than the spending of large sums on protective devices of various kinds.

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An important problem for distribution companies serving sparsely settled districts, especially those in the West, is that of securing small high-voltage transformers, three-phase or single-phase, which will stand up under the line switching, surges, etc., which occur in ordinary operation of a large high-tension system. The companies must generally reach out for all possible load wherever it may be, and it is of prime importance that this subject of small high-tension transformers should receive the greatest possible consideration, as the services usually secured by their use pay the highest price for energy, making it possible for any company to extend its lines to be ready for the business as the country develops. Such transformers only, will make it possible to serve the farming community, which, it is claimed by some, offers the most attractive income now in view for operating companies, because of the fact that once the farmer is connected to the lines, he will remain a customer with increasing energy consumption, with good load factors, and furthermore, the general expense of service such as collections, moving meters, etc., is very much reduced with this class of service, in contrast to the floating population of a great many cities.

Oil circuit breakers are becoming more reliable for high potentials and heavy service, but it is still unwise to attempt to rupture short circuits close to the generators when their combined normal capacity is much greater than 50,000 kw.

While it is generally believed that the electrolytic lightning arresters, as at present developed, are the best in their line that the art affords, it is still quite difficult to make any definite qualitative statements in respect to the protection they actually afford against lightning or other disturbances. Certainly no one would care to take the responsibility of operating stations without arresters, for they are considered to be a form of insurance against trouble; but it would be desirable to have more light on the subject.

### Interferences with Telephone and Telegraph Lines

This is a subject which has been given but little attention, although the problem is a very important one. Nearby telephone and telegraph lines are sometimes made inoperative when any disturbance exists on the transmission line.

A good part of the trouble of the telephone service is due to insufficient insulation. Some of the lines, before long-distance

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transmission was inaugurated, ran through and touched the branches of tree tops which caused leakage in wet weather, and hence unbalanced the wires.

With the troubles due to poor insulation overcome and the transmission line well balanced, no further trouble was encountered except at times of disturbance or interruption on the transmission line. With grounded systems this resulted in the burning out of telegraph relays and blowing fuses on the telephones.

A much more difficult matter to deal with is the making of the transmission company's own private telephone to operate at all times. Usually the telephone line is needed the most at times of trouble and this is just the time when it is out of service, having been put out of commission by the trouble itself.

When providing protection for a recent telephone line paralleling a high-voltage system for a distance of some 300 miles (482.8 km.), it was found that there is no protective apparatus on the market capable of handling the large induced currents which are always present on such lines.

Thus the apparatus had to be built, and was of a very substantial character. The basic principle which was worked upon was to make the line subject, in the first place, to as little trouble as possible by carefully insulating and balancing it with respect to the transmission line circuits. This meant that transpositions had to be placed at frequent intervals. Furthermore, no twigs or other objects were allowed to come into contact with the wire. The usual grounding coils, but designed specially for this purpose were cut in at each station. By these means alone the line was rendered quiet, even though within 60 ft. (18.2 m.) of the high-voltage wires, and conversation could be carried on over a distance of 125 miles (201 km.) with greater satisfaction than over the paralleling commercial circuits. Much heavier fuses were used, for it was not permissible to have them blow out when the circuits were needed most. Discharge gaps were provided, some of these being in vacuum, which gave very good results. The other protection consisted of condensers and choke coils for absorbing the smaller disturbances which would make conversation more or less unsatisfactory. It must not be understood, however, that any or all of these means can be guaranteed to produce a quiet working line, for each case must be studied by itself and methods adopted to meet the conditions.

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## APPENDIX I—DETERIORATION OF PORCELAIN INSULATORS IN SERVICE

BY J. A. BRUNDIGE

While it has been recognized practically since the inception of the electrical art that the commoner insulating materials, such as rubber and compound treated fabrics, are subject to more or less rapid destruction when under the influence of continued electrical stress, the more solid insulating bodies, like glass and porcelain, were looked upon as being permanent in their characteristics and it was considered that they could be relied upon indefinitely to perform their functions. This idea in the minds of engineers has persistently held, even though a few pioneers a number of years ago suggested that it was not impossible that glass and porcelain might be subject to a molecular fatigue when acted upon by electrical forces for long periods, similar to that exhibited by metals under repeated mechanical stresses. Now it is safe to assume that the majority of operating engineers, having to deal with higher voltage transmission lines, have had experiences which lead them to believe in the theory of electrical fatigue in porcelain. Whether this comes about solely through the continued application of the normal operating voltage or whether it is due to the transient overvoltages which are unavoidable on any line, is hard to say, but the existing evidence points to the latter conclusion.

It must not be understood that all or even the greater portion of the failures experienced with suspension type insulators are due to molecular deterioration of the porcelain. A large number of the failures have been traceable to improper design of the insulator parts or to an unsuitable porcelain body.

It has been the experience of a number of transmission companies to have practically no insulator trouble for the first couple of years of operation; then the insulators began to fail in increasingly greater numbers, for no apparent reason. Closer examination, however, sometimes revealed the fact that minute checks had formed all over the surface of the porcelain, and that the failure had been due to a crack extending clear through the shell. This behavior of the porcelain has not been confined to any kind or type of insulator nor to any one manufacturer's product.

The principal requisites for a good porcelain for high-voltage insulators, are high dielectric strength and mechanical toughness. These two qualities are somewhat opposed to each other

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in the actual manufacture, for when a high dielectric strength is obtained, the porcelain is apt to be brittle like glass. It is possible, however, to arrive at mixtures which exhibit both properties to a marked extent when the firing has been properly done, although it is regrettable that some so-called high-voltage porcelains appear to be lacking in both of these properties.

This can be better understood when it is learned that the mixtures used by two prominent manufacturers, each putting out a product which is accepted as reasonably good, vary greatly in the proportion of ingredients employed. While the felspar contents of the two mixtures are of the same order, one has twice as much flint as the other, and the quantities of ball clay and china clay vary as much as three to one. Yet the different manufacturers regard their mixing formulas as trade secrets, and the proportions are religiously followed down to tenths of one per cent. This latter is doubtless done for the sake of uniformity of product, which is important, but until the mixtures more nearly approach a recognized standard, it appears that more or less trouble may be expected with high-tension insulators.

Doubtless, the factor having more to do with the failure of insulators than the porcelain body is the design; or in other words, not only must the electrical characteristics of the insulator, such as puncturing and flash-over values, both of which are highly important, be considered, but also the size and shape of the parts as well. With certain pin type insulators, especially those mounted on metal pins, cracks have been observed in quite a number of the petticoats. These were evidently expansion effects due to temperature changes. The same effects have been noticed to a greater extent with the suspension type insulators provided with metal caps and pins. We have here porcelain, cement and iron assembled together, the coefficients of temperature expansion of the three being quite dissimilar. In this latitude the temperature variation between summer and winter days is well in excess of 100 deg. fahr., and it can be appreciated that enormous internal strains must be set up inside of the caps. The porcelain being the least able to withstand these forces, is the part that suffers and cracks, with the attendant electrical punctures ensuing. In the case of an insulator designed for high mechanical strength in tension, which necessarily means a rather high cap with correspondingly long pin, the temperature changes cause a marked var-

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iation in the length of the pin, which is in contact with the porcelain through means of a layer of cement for a distance of sometimes $2\frac{1}{2}$ to 3 in. (6.3 to 7.2 cm.) along its length. The great strain to which the porcelain is subjected is then apt to produce cracks perpendicular to the axis of the pin, which has actually been found to be the case in a large number of instances. These cracks, however, are mostly very minute and can hardly be detected by the eye if the cap and the cement have been carefully removed. A line of ink drawn over the surface of the porcelain, however, will nearly always disclose the cracks, as the ink will be drawn along them by capillary action.

The method of failure of suspension insulators with metal caps and pins is often quite characteristic. Cracks develop at some point inside the cap, and when the current leakage through them is sufficient, a path is fused through the porcelain by the intense heat generated. If the heating takes place relatively slowly, a hole is apt to be fused through the cap, through which gases and melted porcelain are forcibly expelled, but the insulator usually holds together and continues to support the cable. With a large amount of power back of the break, which may act in the nature of a short circuit inside the insulator, caps have been known actually to explode, in which event the line conductor is allowed to fall. Before the burning of the caps can take place, it is necessary that several of the units of an insulator string be bad, and instances have been observed where all the caps of ten-unit insulators have been so affected. With the better methods for locating cracks and faults as soon as they have developed, such as the high-range megger, the pyrotechnic displays above described have become fewer.

Because of several instances of trouble of this character having recently been observed in connection with suspension type insulators, some engineers have been led to believe that they are unsuccessful, which conclusion is wholly unwarranted.

The high-range megger has proved to be an extremely useful instrument for the locating of insulator faults undiscoverable so far as ordinary means of inspection are concerned. Tests made on a large number of units later checked up by tests with a high-tension transformer, have shown that the megger can be absolutely depended upon if reasonable care is used to see that there is no leakage in the conducting leads. To show the sensitiveness of the megger, the two electrodes can be placed within $\frac{1}{4}$ in. (6.3 mm.) of each other on a glazed porcelain sur-

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face or upon a fractured surface where there is no glaze and the reading will be practically infinity. By blowing the breath upon this surface even when the porcelain is at a moderately high temperature, the moisture so deposited will be sufficient to give a comparatively low reading on the needle. When a crack occurs in the porcelain up inside the cap there is always sufficient moisture present in the cement to give an indication on the needle, which need not be confounded with surface leakage, if the insulator is at all reasonably clean. If the insulators are so dirty that surface leakage is marked, they should be cleaned before the megger test. Certain insulators may give a reading of from 40 to 100 megohms, and if later tested with a high-tension transformer they will not fail immediately upon the application of voltage, but may hold up until 30,000, 50,000 or even 60,000 volts is reached before puncturing. Those which show a zero reading on the megger will stand no voltage from the testing transformer.

An interesting experiment was recently made by immersing a batch of insulators in water at ordinary temperature and slowly bringing them up to the boiling point. Twenty insulators, some two or three years old, were tested in this manner and every one was found to be ruined by the time boiling point was reached. These were from two different manufacturers, one of whom has previously delivered batches of insulators where bringing them to the boiling point of water was one of the routine requirements before the insulators left the factory. Other similar tests made on new insulators of the same design did not produce failure, except in a few units. The probable explanation of this is that in the new insulators the cement had not yet attained its ultimate hardness, and allowed the expansion to take place in the pin without cracking the porcelain.

The data at hand upon insulator failures are unfortunately very incomplete, and until these are collected and have been studied, all designs brought forward must necessarily be lacking in some respect. Enough is already known, however, to indicate the general direction which the new designs will follow, and it may be confidently predicted that the troubles experienced will be materially lessened in the immediate future.

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## APPENDIX II—RADIUS OF INFLUENCE OF A DIRECT LIGHTNING STROKE

BY L. C. NICHOLSON

A lightning stroke to earth at some point adjacent to a high-tension transmission line induces voltages and frequencies in the transmission conductors of sufficient magnitude to affect the insulation of the line, causing either spill-overs or punctures of insulators. The question often arises as to how near the line lightning can strike without affecting its operation. The answer to this question can never be definite, since not only do transmission lines vary in degree of both insulation and lightning protection, but the character and severity of lightning strokes undoubtedly vary between wide limits. General atmospheric electrostatic conditions also have an effect.

Through continued personal inquiry it is possible to arrive at a general estimate concerning the radius of influence of a direct lightning stroke. By noting objects which have been struck by lightning adjacent to transmission lines and comparing the operation of the line at the time the object was probably struck, an opinion can be arrived at, which is applicable to a particular transmission line located in a given lightning belt. Such an opinion undoubtedly would have to be modified considerably to apply to transmission lines of different insulation characteristics and lightning protection and exposure.

Observation and inquiry lead to the following general conclusions on this subject.

1. It is doubtful if any degree of insulation in use at present, with or without the ordinary protective measures, will withstand the effect of a direct stroke of lightning on the line. In such a case the electromechanical forces acting on the porcelain are very high, usually causing insulators practically to explode. It is not unusual in such cases to find insulators shattered into small fragments, many of which are thrown as far as 100 ft. (30.4 m.) from the line. Furthermore, a direct stroke usually envelopes all the conductors of a line and sometimes envelopes several lines located relatively close together. This would indicate that the area of the stroke itself is large, or that it has numerous prongs. Observation of burn marks on conductors which were struck when there was no power on the line indicate by their distribution and extent that the diameter of the stroke was approximately 20 ft. (6 m.) Such being the case it is not surprising that one or more overhead ground wires cannot always intercept direct strokes.

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2. Induced effects from strokes at some distance from the line may, on medium-voltage lines, be of sufficient magnitude to cause flash-over or puncture of insulators. Extended observation of the operation of 60,000-volt pin type insulators, unprotected by overhead wires, leads to the estimate that the radial influence of direct strokes is rarely in excess of 2000 ft. (609 m.) and may be less than 100 ft. (30.4 m.). These are rather wide limits, but the most definite evidence available indicates their probability. It appears that strokes of great severity, 2000 ft. (609 m.), and more in extreme cases, from the line, produce disturbances of operation, while strokes of less severity may occur at 100 ft. (30.4 m.) from the line without producing such results. These last are, however, in our opinion, rare, and a stroke at less than 2000 ft. (609 m.) from the line is apt to cause trouble.

In more highly insulated lines the danger zone apparently decreases substantially, and in the most highly insulated circuits at present in operation it is probable that the large majority of induced effects are insulated and protected against, leaving only direct strokes on the line itself to be taken.

Careful numerical tabulation of lightning effects indicate that direct strokes on the line constitute approximately 10 per cent of all lightning disturbances on 60,000-volt pin type circuits located in New York State.

## APPENDIX III—TRANSMISSION LINE PROBLEMS IN THE WEST

BY P. M. DOWNING

The different power companies operating on the Pacific Coast have done a great deal in the way of pioneering in the transmission of power over long distances at high voltages. This was due, to a considerable extent, to the fact that there is an abundance of water available for the hydroelectric generation of power, and also to the fact that the cost of fuel is very high as compared with that further east.

The first long-distance transmission to be put into successful operation on this coast, if not the first in the United States, was that of the San Antonio Light & Power Company in southern California, at what is known as their Pomona plant. This transmission was for a distance of 30 miles (48.2 km.) at 10,000 volts.

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Transformers were at that time not manufactured for this voltage, and it was necessary to connect in series ten 1000-volt transformers for stepping up. The low-tension windings were connected in multiple.

The first polyphase installation was made in 1893, at Mill Creek, and furnished power to the city of Redlands.

The success of these undertakings gave a great impetus to the hydroelectric industry, and inside the next five or six years, there were several different companies operating at voltages as high as 60,000.

The climatic conditions of the Pacific Coast, and particularly of California, are most favorable to the operation of high-voltage lines. Except in the higher mountain districts, there is practically no snow to contend with, and there are but very few places where lightning ever causes any trouble. Some operating companies have installed lightning arrester equipment, but it is not common practise to do so. The well-known horn gap arrester, one side of which is connected directly to ground without resistance, has in many instances been used to advantage, more as a voltage limiting device than as a lightning arrester. These have proved quite satisfactory for this work. Ground wires strung above the line wires have been used to some extent, but there is so little trouble from lightning that engineers have never been able to decide as to whether or not there is any advantage in using them.

Very seldom, if ever, is it possible to find where an insulator has been punctured due to lightning. This is, possibly, due to the fact that the high voltage dissipates itself over the surface of the insulators. A number of instances is known where lightning has gotten onto the line, burned off one or more wires between poles, and gone to ground without in any way damaging the insulators, and only slightly damaging the wood poles.

The greatest trouble on lines using the ordinary four-part, 14-in. (35.5 cm.) pin type insulators at voltages around 60,000 is that due to leakage over the insulator. The climate of this coast is peculiar in that there are two seasons, one being dry and lasting for six months, the other being wet. During the dry season, and particularly in the sections near the coast, dust and salt fog will accumulate on the insulators to such an extent that leakage will eventually burn off the pole, and sometimes the line wire, without damaging the insulator itself.

Different ways of overcoming this trouble have been tried,

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but nothing seems to improve the condition, except cleaning the insulator. Even this does not entirely overcome the trouble. After the first heavy rains come on in the early winter, the insulators are washed off, and little trouble need then be expected, until they have again become covered. The thing that seems to eliminate the trouble most is to tie the pins together electrically, but not ground them. The grounding has been tried, but with unsatisfactory results, because arcs will oftentimes be established between line wire and ground, which will hold until the voltage drops sufficiently for them to be extinguished.

The regulation of voltages on a high-tension network is not always an easy problem. No one particular point can be selected at which voltage can be kept constant, but it is necessary to keep it as near constant as possible over the entire network. This is accomplished by the use of synchronous condensers located at the more important distributing centers. These condensers can be made automatic by varying the fields. Several such installations are now in satisfactory operation.

The first high-voltage oil switches used at 60,000 volts were put into operation on the transmission lines in this State. The same general type and design that was originally selected as being suitable for 40,000 volts is still being used. On the 110,000-volt lines the same general type, with slight modifications, is also being used. In this particular switch the circuit is opened at two or four points, depending on the voltage and load carried. The contacts are made by rotating blades moving in a horizontal plane. The separate oil containers for each leg of the circuit are insulated from each other and from the ground by means of properly designed porcelain bushings or insulators.

Another very successful design of switch for the same character of service is that using a pantagraph arrangement of links carrying a contact and operated by a vertical movement of one corner of the pantagraph, thus giving a break in a vertical plane. Both of these types of switch have for years been in successful operation under all conditions of load. They have a weakness common to all oil switches, in that when operated under a heavy short circuit they will at times throw oil out of the container.

Outdoor oil switches, either automatic or non-automatic, are being used very generally for branch lines, or for sectionalizing trunk lines. For economic reasons the automatic switches are very often operated by means of a solenoid placed directly in the main line. Such an arrangement does away with the use

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of current transformers, but has the objection that the connection from the movable plunger to the relay, or trip, must stand the entire voltage from line to ground.

As the sensitiveness of the trip is, to a considerable extent, dependent upon the weight of the moving parts, the importance of keeping this weight down to a minimum is apparent. Well-treated rods of sufficient length have been used to make the connection from the plunger to the trip, or relay, but they have not been entirely satisfactory, because sooner or later they cause trouble from burning.

Transformer designs have more than kept pace with the art of long-distance transmission at high voltages, and it is now possible to get satisfactory apparatus for any voltage that can be handled on the lines.

One thing, however, that some manufacturers have failed to give proper attention to is that of supporting the windings to prevent injury or distortion due to mechanical strains set up when short circuits occur. In units of large capacities and high voltages, the coils are generally built of strap copper, using one turn per layer, these turns being separated by one or more thicknesses of insulating material. Obviously, with such a construction, the turns will be easily displaced, unless they are well supported on both sides.

A number of failures have recently occurred where straight vertical separating strips have been used in assembling the coils, thus leaving the turns between these separating strips unsupported throughout their entire length, and allowing them to be displaced when short circuits came on. Shorter strips placed diagonally across the coils, or wave-shaped strips, which will allow a free circulation of oil, will entirely overcome this trouble.

## APPENDIX IV—SWITCHING

BY G. FACCIOLI

Switching produces, in general, an abrupt change in the value of the electromotive force and of the current of the circuit, or of either of these quantities, and therefore it produces a sudden change in the amount of energy stored in the circuit, with the result that oscillations are produced.

The severity of these oscillations depends on the difference between the running conditions before and after the switching is done. For instance, if a dead line at zero potential is suddenly

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connected to an alternating-current generator, the oscillation produced will be most severe when the switch makes the connection at the instant at which the electromotive force has its maximum value. Likewise, if a short-circuited line is disconnected from an alternating-current generator, the oscillation is most severe when the circuit is broken at the instant at which the current passes through its maximum value.

The oscillations are of two kinds: They may occur between inductance massed at one point of the circuit, and capacity massed at another point of the circuit, as for instance, when a dead line which acts practically as a condenser is connected to a generator which acts practically as an inductance, or when a line (capacity) connected at one end to a step-down transformer (inductance) is disconnected from the generating system.

They may also occur between the distributed inductance and capacity of a part of the circuit, as for instance, when a line is disconnected from a generator and the energy stored in the line gradually dies out, changing from electromagnetic energy stored in the distributed inductance of the line, to electrostatic energy stored in the distributed capacity of the line and vice versa, or when an unloaded step-down transformer is disconnected from the line, its windings acting similarly to a line.

These oscillations do not, in general, constitute a great danger to the circuit if the contact in the switch is made once, positively, for every switching operation.

However, if each switching operation is accompanied by arcs, so that the circuit is repeatedly closed and opened, then the pressure rises may become dangerous, and destructive cumulative oscillations may be set up in the apparatus. Furthermore, at the instant at which contact is made, traveling waves are sent out from the point of switching along the line in both directions. These traveling waves with steep fronts follow, naturally, the well-known rules of reflection and refraction, and whenever they strike a localized oscillatory circuit, they excite in it oscillations at its natural period.

For instance, if a dead line is suddenly connected to a live line having the same constants, a " wave of charge," equal in value to one-half of the potential of the live line, starts along the dead line from the switching point. If the dead line is open at the far end, the " wave of charge " is reflected back at double potential, etc., etc. At the same time a " wave of discharge " starts along the live line from the switching point with a value

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equal to one-half of the original voltage of this line. If the live line is connected at its origin to transformers, this " wave of discharge " is reflected back with double voltage and may excite local oscillations in the transformer windings or in the circuits of the power house, etc., etc.

These traveling waves are a source of danger and obviously the danger is increased when sparking and arcing occur in the switch.

It is seen from the above that high-tension switching, which has lately gained so much importance in the art, should be done very judiciously and only when necessary, unless special precautions are taken to avoid the disturbances resulting therefrom.

As a rule, low-tension switching is preferable, as this avoids steep wave front phenomena.

For instance, in energizing a line, it is preferable to connect the dead line to the dead step-up transformer and then connect, by low-tension switches, the line and transformer to the generator, rather than connecting the transformer alone to the generator and then switching the line onto the high-tension winding of the transformer. Of course, in this case it would be still better to connect the line and the step-up transformer and the generator together while the whole system is dead and then bring it up gradually to full potential by the excitation of the generator.

Fuses act similarly to switches, except that the former open under load, while switches are, as a rule, operated at approximately no-load. The sudden interruption of large amounts of current results in considerable over-tensions, and this is the danger that usually accompanies the blowing of fuses.

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# PRACTICAL OPERATION OF SUSPENSION INSULATORS

BY H. W. BUCK

ABSTRACT OF PAPER

The paper describes some of the mechanical and electrical problems which have been experienced on high-voltage transmission lines equipped with suspension insulators and points out some of the principles involved and some practical methods for guarding against the troubles. Figures are given showing the deflections which will take place for various sizes of aluminum and copper conductors at the insulators, under the pressure of maximum probable wind velocity.

THE APPLICATION of suspension insulators to high-voltage transmission lines, since their first introduction in 1905, has been very general on all lines operating at voltages over 50,000, and the results obtained have been in most cases very satisfactory. The change, however, from the rigid pin insulator to a construction involving the free and flexible suspension of the conductor in space is a radical one and the change in practise has taken place with considerable abruptness, so that it is not surprising to have experienced a new class of line troubles. It is the purpose of this paper to point out a few of the difficulties which have been experienced, with the hope that a discussion of the subject may lead to improved standards of construction for such lines.

In the pin insulator line the conductor is held rigidly at every insulator, consequently lateral and longitudinal movement of the conductor is resisted at every point of support. Suspension insulators, however, except at dead-end connections, are free to move in all directions. The result is that high winds occasionally cause displacements which are electrically and mechanically dangerous to the operation of the line. Deflections of suspension insulators from the vertical position result also from other causes, which will be discussed later.

Large angular deflections of suspension insulators require large clearance spaces, which necessitate long crossarms and increased cost of tower. Consequently it is desirable to limit the deflection as far as possible. A 60-deg. angle from the ver-



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tical is assumed to be the maximum allowable under extreme conditions.

In order to show how nearly the above limitation can be attained in practise. Table I is given, indicating the deflections caused by wind pressure on various sizes of conductor, at the insulator. The wind pressure assumed in the table is 15 lb. (6.8 kg.) per sq. ft. (0.09 m.) of projected conductor area, which is taken as the maximum. Wind pressure deflections are practically independent of span length, since wind pressure per span and the force which resists the wind pressure, namely, the weight of the conductor, both vary directly with length, in the same proportion.

TABLE I

| A Size conductor | B Wind pressure | C Angular deflection | D Auxiliary weight |
|---|---|---|---|
| | STRANDED COPPER | | |
| 4 | 15 lb. | 66 deg. | 0.011 lb. |
| 3 | 15 " | 63 " | 0.028 " |
| 2 | 15 " | 60 " | 0.0 " |
| 1 | 15 " | 58 " | 0.0 " |
| 0 | 15 " | 55 " | 0.0 " |
| 00 | 15 " | 52 " | 0.0 " |
| 000 | 15 " | 49 " | 0.0 " |
| 0000 | 15 " | 45 " | 0.0 " |
| | STRANDED ALUMINUM | | |
| 2 | 15 lb. | 81 deg. | 0.156 lb. |
| 1 | 15 " | 79 " | 0.161 " |
| 0 | 15 " | 78 " | 0.171 " |
| 00 | 15 " | 77 " | 0.182 " |
| 000 | 15 " | 75 " | 0.186 " |
| 0000 | 15 " | 74 " | 0.196 " |
| 250000 | 15 " | 72 " | 0.190 " |
| 300000 | 15 " | 71 " | 0.177 " |
| 400000 | 15 " | 68 " | 0.158 " |
| 500000 | 15 " | 66 " | 0.125 " |

Experiments have shown that the weight of the string of suspension insulators themselves will not act to resist wind displacement of conductor, since the exposed surface of the insulators is sufficient to cause their deflection by wind pressure without the attachment of the conductor. Neither will the deflection vary appreciably with the size and design of the insulators, since a heavier insulator ordinarily exposes a larger "sail area." The wind displacement of conductor can therefore be assumed to be independent of the number of insulators in the string, and of their particular design.

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Table I indicates approximately the wind deflections which will take place for various sizes of conductor under a stress of wind equal to 15 lb. per sq.ft., as above. Two tabulations are given, one for copper, and the other for aluminum.

In Table I, column A shows the conductor size in B. & S. gage. Column B gives the assumed wind pressure in pounds per square foot of projected cable area. Column C gives the angular deflection of the insulator from the vertical, due to the assumed wind pressure on the conductor, assuming that the insulator itself deflects independently and neither increases nor decreases the displacement of the conductor. Column D shows the amount by which the weight of the conductor would have to be increased in order to reduce the deflection of the insulator under the assumed conditions to within the 60-deg. limit.

It will be seen from an inspection of the table that all sizes of copper except the smallest sizes listed, namely, No. 4 and No. 3, will ballast the insulators sufficiently to keep the wind deflection down to within 60 deg. A line of No. 4 B. and S. wire, it will be noted, is deficient in weight to the extent of 0.041 lb. per ft. and No. 3, 0.028 lb. per foot.

On the other hand, all the sizes of aluminum cable listed will allow deflections in excess of 60 deg., and especially among the smaller sizes, objectionable displacements will occur. Under these conditions one of the chief supposed advantages of aluminum, namely, its lightness, becomes its disadvantage, and the actual ballasting quality of copper due to its higher specific gravity and smaller size is a distinct advantage.

The larger sizes of conductor are more stable mechanically against wind deflection, since their weight in proportion to the surface exposed to wind is greater than in the small sizes, the weight increasing as the square of the diameter, whereas the wind pressure is only directly proportional to the diameter.

Fig. 1 shows a method for reducing deflection which has been adopted on an aluminum transmission line in the South, about 200 miles (321.8 km.) in length, which has produced satisfactory results. The line is of No. 0 B. & S. aluminum cable, with an average span length of about 300 ft. (91.4 m.) An auxiliary weight made of cast iron is attached to the lower side of the suspension clamp at every insulator. It is consequently placed at a point where it is most effective as ballast. This arrangement results in very satisfactory stability of the line under all conditions.

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Column D, Table I, shows the auxiliary weight which must be added at each insulator for the proper stability, expressed in pounds per foot of span. In the opinion of the writer, auxiliary weights of this kind should be provided on all aluminum lines using suspension insulators and on all lines where the smaller sizes of copper are installed. The auxiliary weight not only stabilizes the line against wind pressure but improves its operation in many ways, such as in resisting longitudinal movement of insulators under unbalanced pull due to a breakage somewhere along the line. It also improves conditions where a gust of wind strikes a single span independently, in reducing the slack which can be taken from adjacent spans due to unbalanced pressure.

A curious and unusual phenomenon has been experienced on at least one suspension insulator transmission line known to the writer, and is illustrated in Fig. 2. A severe sleet storm had occurred along the line during the night and all the conductors were covered with a heavy coating of sleet. When the sun came out in the morning the sleet started to melt, but it did not, naturally, fall off all spans of the conductors simultaneously. The condition illustrated in Fig. 2 occurred. Sleet has melted and dropped off spans $B_1$ and $B_3$, leaving span $B_2$ loaded and all other conductors in normal position, either sleet-covered or otherwise. Span $B_2$ will then sag down, taking slack from adjacent spans and will come in contact with conductor $C_2$, causing a short circuit. Such a combination of circumstances, although unusual, might happen on any suspension insulator line where the conductors are disposed in the vertical plane, and should be guarded against.

On long tangents on a suspension insulator line where there are no dead-end connections installed, if a very high wind strikes the line at an angle of about 45 deg. cumulative waves like the waves on the surface of the water have been observed to travel along the conductors of the line, causing a whipping action at all suspension insulators, the waves finally "breaking" as on a beach at the first dead-end connection met. This phenomenon cannot occur on a pin insulator line, since the line is confined at every crossarm. This trouble can be prevented by dead-ending the line at frequent intervals.

The methods of dead-ending suspension insulator lines as at present practised cannot be considered satisfactory. There is a wide margin for improvement in the design of the mechan-

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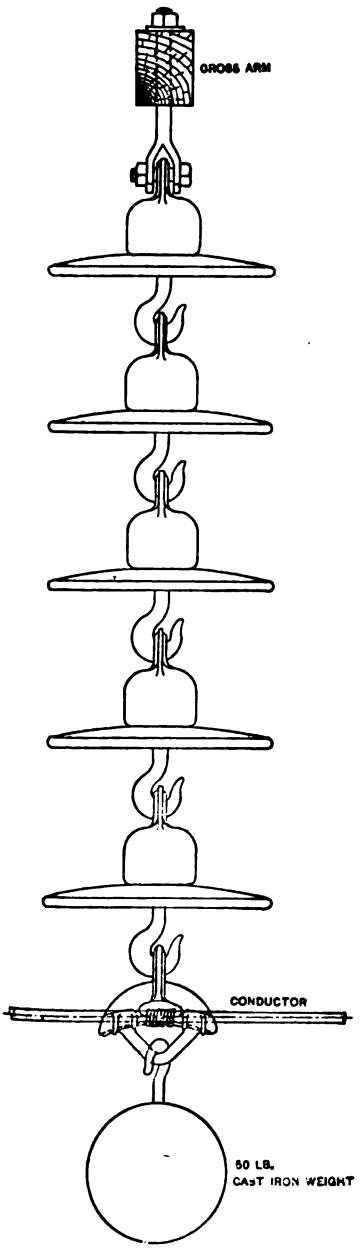


FIG. 1

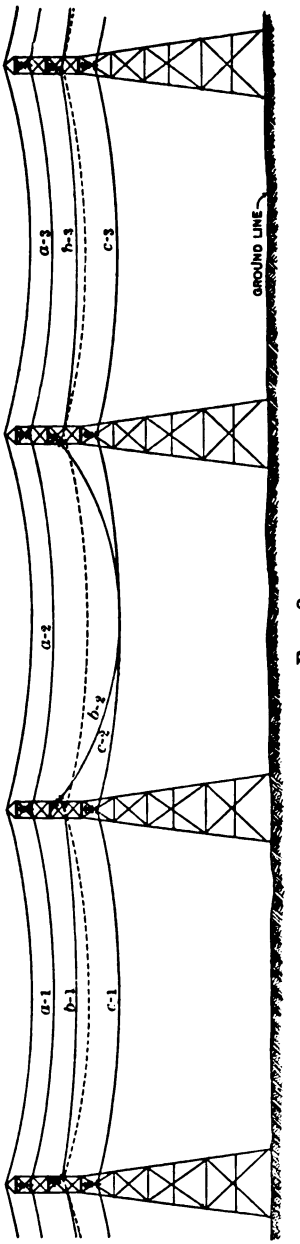


FIG. 2

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ical fittings used for the purpose, especially in providing means for preventing the lateral swing of the jumper connection. Here, too, some form of ballast weight might be used to advantage.

In the experience of the writer the suspension insulator units which have given by far the best service over a long period of time are those of the simple general form shown in the assembly in Fig. 1. The design of these disks is entirely free from corrugations, flanges, petticoats, etc. While such devices increase the resistance of the insulator to surface leakage and surface arcing, the complexity of form seems to introduce internal shrinkage stresses in the process of moulding, firing and cooling, which in time, due to sudden temperature change or mechanical shock, will develop into puncturable faults. The insulator of simpler form is cheaper and more can be installed in series at the same cost and with the same electrical factor of safety as with a fewer number of disks of a more elaborate and expensive design.

In general, most of the troubles which are being experienced in the various suspension insulator lines built to date can be overcome by the following precautions:

1. Provide liberal clearance between conductors and between conductors and supports. This should be considerably more than good practise would require in a pin type insulator line.

2. Install the lightning ground wire, if used, high above the conductors, so that no combination of gusts of wind can whip the conductor into it when suspension insulators are deflected to the maximum angle.

3. Place auxiliary ballast weights at every suspension insulator where aluminum cable is used and with the smaller sizes of copper.

4. Design the jumpers and fittings at the head-end connections so that the jumpers cannot possibly become displaced and come into contact with the crossarm.

5. Draw the conductor up tight throughout the line. A too conservative allowance of slack to guard against possible mechanical stresses in the conductor will cause more trouble than it will prevent.

The insulating properties of suspension insulators have proved adequate for all line voltages so far attempted up to 150,000 volts, and the satisfactory results have been attained within reasonable mechanical dimensions of insulators. The insulating

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units shown in Fig. 1, which are about as small as any made, electrically or mechanically, being merely 10 in. (25.4 cm.) disks of plain surface, will arc over "dry" at about 80,000 volts and "wet" at about 50,000 volts. The arc-over voltage is well under the puncture voltage. Insulating units of more elaborate design will withstand considerably higher voltage tests. Mechanically, such insulators will withstand tension stresses of at least 5000 lb. (2268 kg.)

In determining the proper number of disks to be strung in series it is advisable to install the number required for the desired factor of safety and then to add at least one disk for reserve against breakage. In other words, the insulator should have a sufficient number of disks in series so that in case one or more are broken or punctured the remaining intact disks will afford a sufficient margin of insulation for safe operation until such time as the broken disks can be replaced.

On this basis, assuming an insulation factor of safety of two, an 80,000-volt line would require four of the disks of Fig. 1, 100,000 volts, five disks, and so on for higher voltages. These results are interesting for comparison with the probable cost, mechanical dimensions and strength of a pin insulator which might give equivalent results.

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# DISTRIBUTION OF ELECTRICAL ENERGY

## REPORT OF SUB-COMMITTEE ON DISTRIBUTION

P. JUNKERSFELD, CHAIRMAN

IN THIS report your committee has submitted an outline of what it believes to be good engineering practise in the distribution of electrical energy for various purposes and under various conditions, which outline it is hoped will encourage and direct further attention to this vitally important matter.

The distribution of electrical energy in a given area, like the distribution of any raw or manufactured product, any commodity or utility, depends fundamentally upon the density or number of points of consumption or of use within the particular area. Other things being equal, any given method of distributing electrical energy should afford better results, reliability and economy, in the denser of two equal areas.

In practise, all other conditions, as well as areas, vary widely because electrical energy is used for so many different purposes and in such rapidly increasing quantities. Electrical energy should be distributed in such form and at such voltage as will produce the best final result, all things considered, and each given proper weight. A full consideration of best final result immediately involves economic questions beyond the limits of this report, including the generation of electrical energy for practically every purpose by interconnected power houses under unified operation. The advantage of unified operation of power houses has, however, been thoroughly demonstrated and is quite generally recognized in this country and abroad. In all such cases most of the electrical energy required in a given area or community is usually generated in relatively large economical power houses and, to secure the best result in distribution, in such form as will best lend itself to meet the predominating demand in that community.

Such unified operation or centralized generation of electrical energy has so far usually been limited to power houses, and in



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some cases includes the transmission to substations. In a few cases this centralization has recently been carried a step further to include the substation. In one of these cases, very large amounts of electrical energy had been supplied by the electric power company to each of two competing metropolitan railway systems, one elevated and the other operating on the street surface, both serving the same territory (the north and west sides of Chicago) and each operating its own substations independent of the other railway system. Supplementary contracts have recently been made under which the power company leased all of the substations of the elevated railway system and then contracted to exchange conversion service with the surface railway system. The power company also agreed, with necessary limitations, to build new substations where needed to deliver 600-volt direct-current energy to either of the above two systems.

As a result, the elevated railway system in this territory will be supplied very soon from 13 distributing substations instead of seven as formerly, and the surface railway system in this territory from 18 distributing substations instead of 10 as formerly. The average feeding distances are thus even at the start almost cut in half and make possible very large savings in distribution. Four of the additional substations are owned by the power company and will be also used for distribution of electrical energy to its general lighting and power customers, thus making a further saving in distribution investment and operating expense in that community.

In one of the cases above mentioned, a single substation with 4000-kw. synchronous converters supplies 600-volt direct current to three different railway systems, where under former methods three separate small substations would have been necessary. In another, direct current at 250 volts to a three-wire Edison system and at 600 volts to surface railway systems, is delivered from one substation instead of two. In both cases the investment in high-tension cables from the power house, in substation land, building and equipment, was about one-half what it would have been if the two or three separate substations had been built in each case. This reduction in investment results from: (1) less reserve high-tension cable; (2) less land and building for one large substation than for two or three small ones; (3) less cost per unit of substation equipment because of larger units; (4) less cost per unit of demand in kilo-

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watts on one substation than on two or three, because of considerably lesser amount of spare capacity in kilowatts to give equally reliable service.

The operating expense for the one large substation was practically no more than the operating expenses for each of the two or three small ones, thus reducing these expenses one-third and one-half, respectively, in the two substations referred to.

In the above cases the high-tension supply to the substations was all at 25 cycles. Almost the same possibilities for economy exist in many cities where the general supply is at 60 cycles, as 60-cycle synchronous converters have now been developed to a point where in all except possibly the very largest units they are comparable with 25-cycle synchronous converters.

This tendency of utilizing as many substations as possible for distributing all electrical energy (of whatever form or voltage) required within the economical radius of each substation, must result in large savings in future. Especially is this true when we realize that today only about one family out of four in this particular territory of rapidly growing population is enjoying the use of electric service. The possibilities in demand for electrical energy in transportation and industrial work in this particular territory seem equally promising.

The great importance of the subject of distribution of electrical energy is further indicated by the fact that in the average centralization system in a large city the fixed charges and operating expense of the distribution system are nearly three times the fixed charge and operating expense of the power house. This includes all equipment and conductors between power house switch gear and the customers, premises and refers to kilowatt-hours sold for general light and power, exclusive of bulk supply.

All expenditures of every kind for electrical energy for every purpose in any community should be viewed from the standpoint of such community, because that community in the end reaps most of the benefits, if any, and suffers most of the losses, if any, that result from the particular manner in which electrical energy is generated and distributed in such community. The advantage of centralization in generation of electrical energy is generally recognized, but the advantages of some centralization in transmission and in the substations is not so well understood.

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In addition to the centralization of electric power generation, the centralization of distribution, at least the transmission to substations and the conversion therein, should always receive the most careful consideration.

The use of a single substation building for distributing electrical energy reliably and economically for general lighting and power, for surface railways and for elevated railway trains, has already been demonstrated. It is only a small step farther to distribute 600-volt direct current for steam railroad terminal operation from the same substation. If necessary, 1200-volt instead of 600-volt direct current could be distributed from the same substation and still effect a considerable saving if enough foresight and breadth of view is exercised by all parties interested.

Beyond the substation it is also very desirable to have centralization, at least to the extent of a single system for all general supply. The wastefulness of two different systems of mains for general supply overlapping in the same area, is quite generally appreciated. Different systems have, however, been well standardized for different conditions as, for instance, the Edison three-wire system for the denser portions or business districts of large cities, and the alternating system for practically all other general supply. In addition, there are various problems in distribution that are peculiar to the particular purpose for which the electrical energy is used.

In the following sections several of the most important problems in the distribution of electrical energy have been treated by members of the Committee who have had particular experience in these problems, which are as follows:

Three-wire d-c. distribution, by P. Torchio.

Alternating-current distribution, by H. B. Gear.

The relation of consumers' apparatus and wiring to distribution, by H. Goodwin.

D-c. distribution for surface lines, urban service, by R. H. Rice.

D-c. distribution for underground and elevated railways, by E. J. Blair.

D-c. distribution for interurban and steam railroads, by W. G. Carlton.

A-c. distribution for interurban and steam railroads, by W. S. Murray.

The relation of distribution problems and switching equipment, by E. B. Merriam.

Distribution for street lighting service, by P. M. Lincoln.

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This report, including the sections and references therein to other contributions on the distribution of electrical energy, is supplemented by a list of references to such contributions from American and foreign authors as have been put into book form or have not been presented before the American Institute of Electrical Engineers. This list of references on the subject of distribution of electrical energy it is hoped will supplement to some extent the recently published Index to the TRANSACTIONS of the American Institute of Electrical Engineers—1884 to 1910 inclusive.

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## APPENDIX I. THREE-WIRE D-C. DISTRIBUTION

BY PHILIP TORCHIO

The modern three-wire d-c. distributing systems consist essentially of a three-wire network of distributing mains fed by a multiplicity of cable feeders delivering current at different points of the network of mains, and a system of substations supplying the current to the feeders.

With the exception of the former low-tension d-c. generating stations which have been replaced by the modern substations receiving high-tension alternating current and transforming it into low-tension direct current, the complete three-wire distributing network of over 25 years ago is still giving in every respect its full 100 per cent service alongside of all subsequent additions. This is almost a unique instance of permanency of usefulness of electrical apparatus used by central stations.

### Feeders and Mains

The current was formerly distributed underground by Edison tube feeders, but in the last 15 or 20 years the cable system has superseded the former tube systems. For feeders, concentric cables with pressure wires are often used, they being either armored and laid in the ground, as is done mostly abroad, or being drawn into subway ducts, as in this country. In other cases single-conductor cables are used with pressure wires in the main cables or separate pressure wires outside. The network of mains consists of three single-conductor cables, of equal copper cross-section, drawn in distributing ducts in the

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streets near the curb line or sometimes under the sidewalk. This system of mains is interconnected at each street crossing, thereby making a solid meshed system. Feeders, which are laid from the station to a number of suitable points, end at a junction box into which enter the feeder cable and pressure wires, and from which issue the main cables tying to the network of mains meeting at that intersection of the street. The junction box may be installed in the manhole or just outside in the street. The neutral main cables are spliced together and grounded at frequent places; in addition, there are neutral feeder cables starting from the substation and going to different points on the system with frequent grounds and taps to ramifications and to the neutral mains. The total amount of copper for neutral feeders is about one-twelfth of that for positive and negative feeders.

In a large system the amount of copper for feeders and mains in per cent of the total is as follows:

| | |
|---|---|
| Feeders positive and negative | 58.9 per cent |
| Feeders neutrals | 4.8 " " |
| Mains positive and negative | 24.2 " " |
| Mains neutrals | 12.1 " " |

## Subway Ducts

Fig. 1 shows an arrangement of manhole, feeder junction box, trunk ducts and distributing ducts with a service handhole. Handholes are placed at convenient places along the distributing ducts and service connections are made to the adjoining buildings by tying service cables to the mains as indicated in the drawing.

These service cables are drawn in an iron or fibre pipe laid in the ground and ending in the basement or cellar of the building to be supplied.

## Service Connections

At the customer's service the supplying company places a disconnecting switch and protective fuses and its current registering and metering devices.

Fig. 2 illustrates a type of modern service connection for lighting and power, consisting of specially designed porcelain blocks, which are equipped not only with fuses and all the connections to the watt-hour meters, but also with clips, by means of which the testing of the watt-hour meters on the customer's premises can be readily accomplished by inserting a plug with connections to the testing apparatus, thereby avoiding inter-

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ference with the supply of current to the customer while the test is being made.

All of these appliances are enclosed under covers which are locked and sealed. From this point the customer derives his supply, three-wire for lighting and two-wire for power, which services are usually metered independently.

## Standard Voltages

The usual distributing voltages used in this country are, $2 \times 110 = 220$ to $2 \times 120 = 240$ volts, though in a very few instances $2 \times 220 = 440$ to $2 \times 240 = 480$ volts are used.

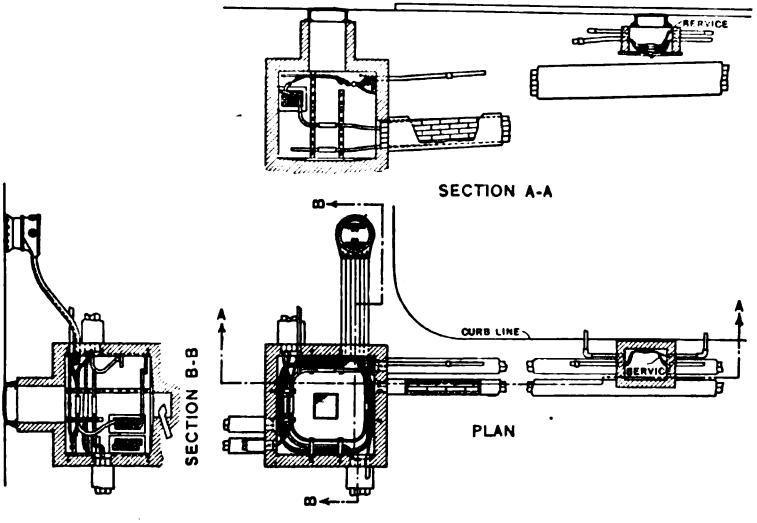


Fig. 1

If the multiple tungsten lamp eventually encroaches into the field of the arc lamp, the advantages of first cost and greater radius of the higher voltage systems would assume greater prominence than heretofore.

## Substations

In general the full double voltage is generated by the converters or the motor-generator sets at the substation and the neutral of the system is secured by several means, among which are storage batteries, balancer sets, derived neutral from transformers, and other means.

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Fig. 3 gives a diagram of the principal elements of a substation. The leads of the positive and negative connections are brought to separate boards. The neutral connections are made not at the board, but in the basement of the substation

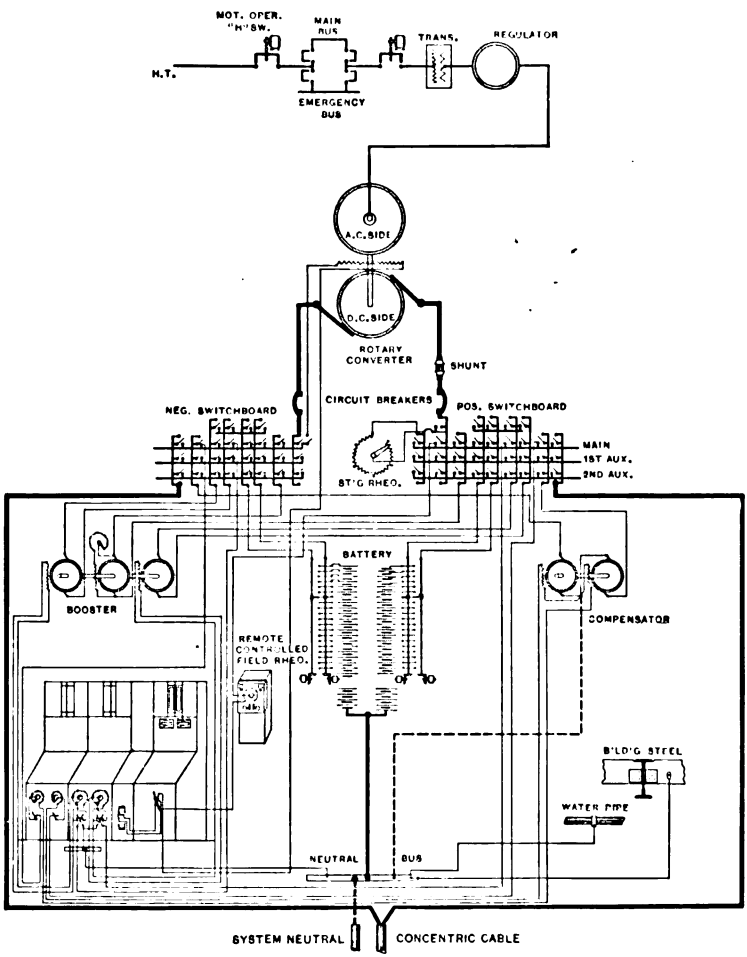


FIG. 3

or in the cable vault. Each of the two separate positive and negative d-c. boards is equipped with multiple buses, and all the feeder switches are selected to connect to any of these several buses. By this arrangement according to the load requirements different machines can be operated on different buses at dif-

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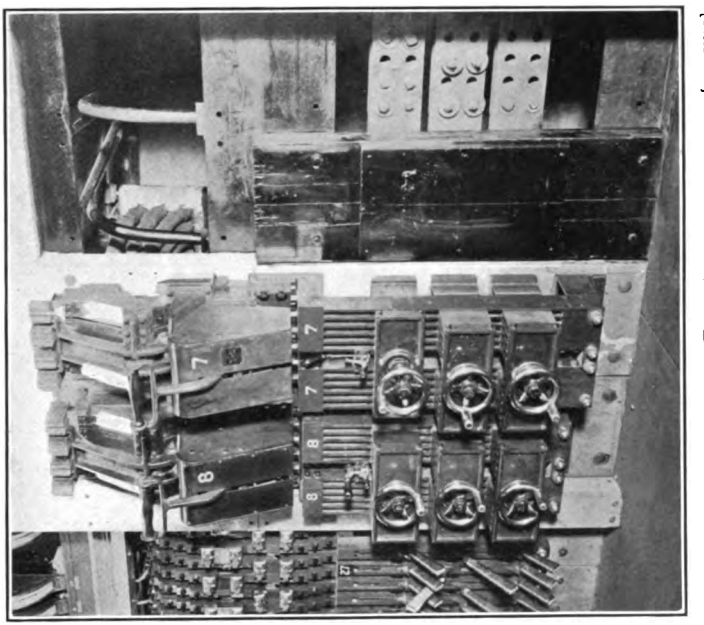

FIG. 4 [TORCHIO]

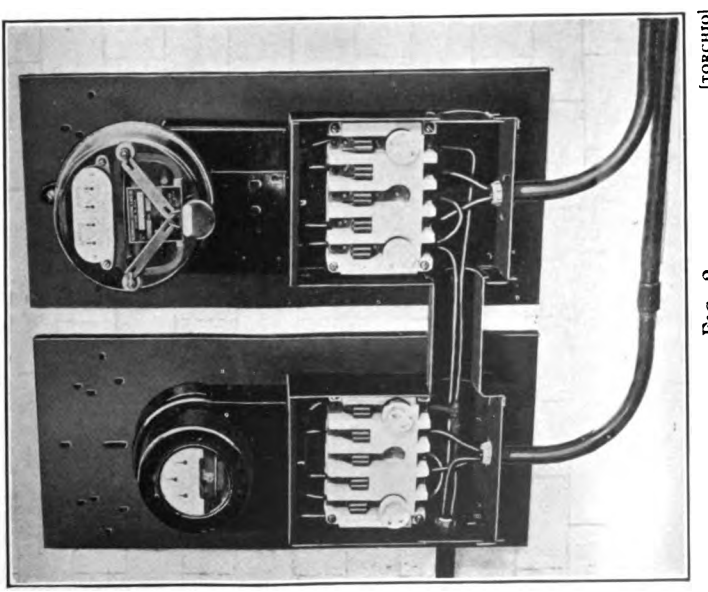

FIG. 2 [TORCHIO]

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ferent voltages, and the shorter feeders can be connected to the low-voltage buses and the longer or more heavily loaded feeders to the higher voltage buses, thus securing voltage regulation throughout the network.

Fig. 4 illustrates the type of these selective switches used for converters and feeders, and the method of installation. By means of this edgewise system, the space occupied by the d-c. switches is reduced to a minimum, so that amounts of power as large as 30,000 kw. at 240 volts can be distributed from one substation.

The references give valuable material on the modern tendencies in substation design and equipment which cannot be treated fully in a brief review of this kind. We may mention, however, a few features of the latest developments which made possible large improvements in economy and simplicity of station. Among them stands foremost the development of the commutating-pole synchronous converter. This, in conjunction with graphite brushes with slotted commutators and self-lubricating copper graphite brushes for the collector rings, has made the operation of synchronous converters practically independent of attendance, except for the starting up and shutting down and the periodic cleaning and setting after the machines are shut down. Other important innovations have been the split-pole synchronous converter and the synchronous booster converter for obtaining regulation.

The manufacturers have produced units as large as 4000 kw. and they are now prepared to furnish still larger units if desired. Converters are usually six-phase and have been in many cases operated with double delta connection, though from recent tests it would appear that diametrically connected converters will operate practically under the same conditions as a double delta connected machine, and still have the advantage of greater simplicity of connections between transformers and converter. The synchronous converters are usually started from the d-c. end.

Air-blast transformers have been used most extensively and the practise of one large company is to have the blower motor connected directly to the secondaries of the transformers, so as to start it when the transformer is energized.

## Storage Batteries

The installation of storage batteries at substations is a distinctive feature and great progress has been made in the last

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few years in the adoption of the stand-by batteries, consisting of very thin plates, similar to those used for electric vehicles. These batteries can give for a short period of time large current discharges and often are designed to give, say for ten minutes, the full output of the substation in case of emergency.

Material improvements have been made in the method of end cell switch controls and connections.

### Control

In very large systems great care is given to a number of such details, like the standard voltmeters for regulating purposes; the station lighting and power supply from duplicate sources; the telephone connections to the generating stations through independent lines and public telephone exchanges; and the emergency signals controlled from the generating station, giving simultaneous instructions by code to all the substations on the system.

## APPENDIX II. ALTERNATING-CURRENT DISTRIBUTION

BY H. B. GEAR

The distribution of alternating current will be considered to include both *bulk supply* and *general distribution*. In the larger cities where the general distribution is made from substations, the bulk supply of energy is distributed by means of three-phase alternating current from the source of power to the points of distribution where it is converted to the form required for general purposes, for street lighting or for railway purposes. These lines are so numerous, and are so related to each other through tie lines, that they constitute a magnified form of distributing system with problems peculiar to themselves, which require consideration which might be lost sight of if they were classed as transmission lines.

Bulk distribution systems will be considered without regard to whether the energy is used for alternating-current distribution, direct-current distribution, or electric railway work after its conversion.

### Bulk Distribution

These systems are quite universally operated on the three-phase system at 25 or 60 cycles and at 6600 to 20,000 volts. The lower voltage is used where the radius does not exceed six miles (9.6 km.) and averages much less. In some systems the

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longer lines have been raised to 20,000 volts or more, to handle the supply to suburban districts more flexibly. In the vicinity of Berlin there is an extensive 30,000-volt cable system serving the outlying parts of the city and suburbs. The German and English cable manufacturers have apparently been very successful in the production of cable for voltages above 20,000 volts, and such transmission lines are placed underground much more generally in Europe than in America.

The choice of frequency is fixed by the relative proportion of energy converted to direct current through synchronous converters. Where the direct-current load greatly predominates, 25 cycles is used and frequency changer sets furnish the alternating-current supply at 60 cycles. Where the alternating-current distribution predominates the power supply is often generated at 60 cycles. In several cases both 25 and 60-cycle generating systems are maintained; reserve capacity for each being secured through frequency changers.

Bulk supply systems have been developed in America chiefly on the principle of radial lines. A radial system is built up by the use of direct lines from power station to substation, one such line usually being sufficient to carry the load when the substation is established. The reserve source of supply, which is imperative, is usually secured by a tie line from another substation; or, in case of a small substation, by tapping another direct line at a convenient point. These conditions are illustrated in Fig. 5, which shows methods of supplying three substations of moderate size. In the three cases here shown it is assumed that the direct lines have a capacity of about 3000 kilowatts.

In cases *A* and *B* the failure of either direct line is provided for through the reserve tie lines. In case *B* a tap connection to one of the direct lines is used to save unwarranted cable investment. Either of the direct lines carries the entire load in conjunction with the tie lines in case of the failure of the other.

Case *C* shows the development of case *A* after the combined load of the three substations exceeds the capacity of a single line.

The ring system of case *A* may be used to take in any number of industrial power consumers up to the capacity of the cable; the substations in this case being on or very near the customer's premises.

The transmission system of one of the large companies in America has been developed on the principle of duplicate lines

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arranged with substations in tandem. The converting units in each substation are divided into two sections so that an interruption on either line interferes with only one-half of the capacity in operation. These lines are protected by overload circuit breakers actuated by definite time-limit relays, so set that they will operate in tandem; that is, only that part of the service is interrupted which is beyond the fault in the cable.

As the loads increase and require more lines, the importance

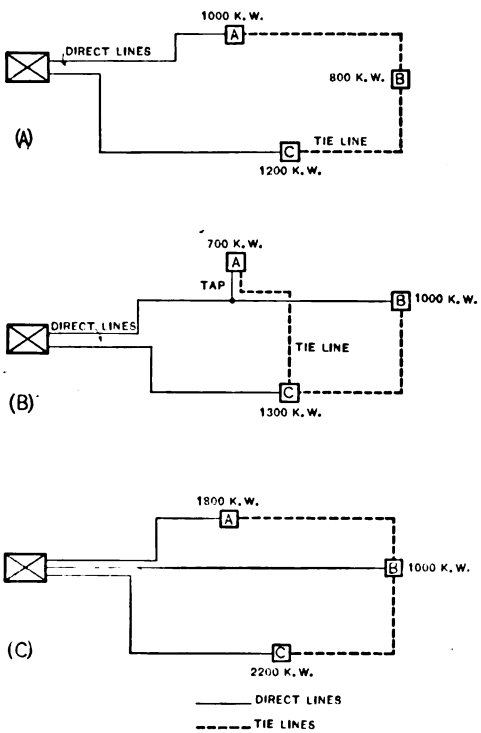


FIG. 5

of having a diversity of routes to guard against the failure of two or more cables to the same substation becomes apparent. This condition is illustrated in Fig. 6. The congestion near the power station must be guarded against by limiting the size of duct runs and providing several separate conduit routes.

As substation loads increase, the percentage of reserve investment becomes smaller, as one reserve line is sufficient for the three substations. Thus the reserve investment is about

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one-eighth of the total in Fig. 6, whereas it is about forty per cent in Fig. 5.

It is usual to provide a transfer bus at substations so that any line can be connected to either tie line or to any converter.

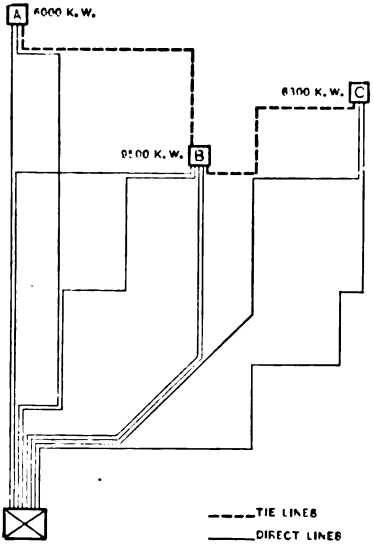


FIG. 6

A large proportion of the lines making up bulk supply systems in large cities is placed underground in lead-sheathed three-conductor cables drawn into ducts. The most economical use of capital is made when such cables are as large as can be properly handled. The kilowatt capacity of a high-tension cable at a given voltage increases more rapidly with increasing sizes of copper, than the cost of the cable. The most economical cost per kilowatt, therefore, requires the use of as large a cable as it is practicable to draw into a standard $3\frac{1}{2}$-in. (8.9 cm.) duct.

The following table gives the maximum sizes of three-core cable which are installed at the present time and their approximate continuous capacity at various voltages:

| Volts | Size of each core | Amperes | Kv-a. |
|---|---|---|---|
| 6,600 | 350,000 | 290 | 3,200 |
| 9,000 | 350,000 | 290 | 4,500 |
| 13,200 | 250,000 | 220 | 5,000 |
| 20,000 | 150,000 | 145 | 5,000 |

The current values are taken for average conditions. They are somewhat high for situations where the facilities for heat radiation are poor, or where there is a considerable number of other cables liberating heat in the same duct line. These amounts of power could also be exceeded for a few hours during a peak load, without risk of injury.

Previous to the last two or three years it was not always

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satisfactory to operate high-tension lines in parallel at the substation end, since a fault in either of the cables supplying a substation is likely to open the circuit breakers of cables not affected, thus shutting off the entire supply. This was due to the absence of reliable reverse-power relays which would permit the most satisfactory parallel operation.

Prior to the development of the commutating pole converter, the largest unit which was considered advisable had a capacity of 2000 kw. These machines were designed to carry 2500 to 3000 kw., however, for about two hours. It therefore became common practise to have a line for each 2000-kw. converter or for two machines where 1000-kw. units were installed. Thus the average load per cable was about 2000 kw. under normal operating conditions, and as the cables used had a capacity of 3000 to 4500 kw., there has been an accumulation of surplus cable capacity amounting to from 50 to 80 per cent of the maximum substation load. This is particularly true of substations having loads above 4000 kw. The situation is such that there is, at the present time in Greater New York and Chicago, not far from $1,000,000 worth of surplus cable investment which could have been saved if means for parallel operation of cables and larger converting units had been available prior to 1910.

The introduction of converting units of 3000- to 4000-kw. capacity for direct-current work and three-phase transformers of almost any desired capacity for alternating-current distribution has done much to improve this condition in recent years. These units permit the use of cables at a point near their full safe carrying capacity and make possible large savings in future cable investment.

Another source of relief has appeared in the development of protective relays designed to permit lines to be operated in parallel. The Merz-Price system has had large and successful application in the north of England in a field where its value is greatest; that of the distribution of industrial power in blocks of 200 to 1000 kilowatts by means of a high-tension network. This system unfortunately involves the use of pilot wires which, not being included in existing cable systems, makes its introduction more expensive and difficult than a system of reverse-power relays. (An interesting modification of the Merz-Price system, in which so-called "split conductors" render unnecessary the use of pilot wires, has been developed in England; but so recently that little definite experience is available.) How-

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ever, it is probably the most reliable means at present known of guarding against interruption of service by cable faults.

Modified forms of reverse-power relays have been developed within the past two years, some of which are under trial at the present time. The performance and further development of these devices will be watched with the most sympathetic interest by all who are interested in getting high-tension cable investments down to a basis of economy comparable with other reductions made in plant costs in recent years.

## Alternating-Current Substations

The alternating-current substation, in its simplest form, consists of a set of transformers with a minimum of switching equipment and auxiliaries mounted outdoors. After the load has grown so that two or more distributing feeders are necessary, circuit breakers, potential regulators and instruments must be added if first-class service is required. These require a building, the character of which is dependent upon the location and relative importance of the substation.

In substations of 1000 kw. or less it is usual to find oil-cooled single-phase transformers. With larger sizes, air- or water-cooled units are more economical. In three-phase systems three-phase units are often employed in sizes of about 750 kw. and upward. In two-phase systems which are operated in connection with three-phase transmission lines single-phase transformers are selected for the Scott connection.

When the power supply is generated at 25 cycles the frequency-changing motor-generator becomes a factor. This usually involves synchronous motors and introduces exciters, starting compensator and necessary accessories in the way of switchboard equipment. Motors of frequency changers are usually wound for the transmission voltage to save transformer investment where the transmission voltage is not above 15,000. Induction motors are used in some cases to secure greater stability at times of system disturbance.

The induction type regulator has largely superseded the transformer type. The superior results secured from automatically controlled regulators in the regulation of pressure has made them standard for important lighting service. The details of line drop compensators, contact-making voltmeters, and motor control have undergone a steady evolution in the right direction in recent years. The adjustment of springs and condition of

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contacts, however, still require periodical inspection and checking of pressure at feeder ends. In Chicago it is found necessary with some 200 sets of equipment to check each of them at least once in three months by the installation of recording voltmeters for a few days at the feeder end.

The improvements in transformer design, by which weights and costs per kilowatt of capacity have been reduced, and the increasing requirements of good service, have made some striking changes in the cost of transformer substations. The transformers, which one ordinarily thinks of as the chief item, constitute less than one-third of the cost of a modern 5000-kw. substation, housed in a fireproof building and equipped with the required quota of oil switches, automatic regulators, duplicate buses, instrument and control panels, etc. The automatic regulators, feeder switches and distributing buses make up about half the total cost. A large part of the facilities of a modern substation is necessary for the safety of operating and construction men whose duties must be performed without accident to themselves or to the service and equipment.

## General Distribution

The distribution of alternating current for general commercial purposes is accomplished in America almost universally by 2200-volt mains supplying step-down transformers located near groups of consumers whose premises are served by secondary mains at 110-220 volts. There are a few installations of low-tension alternating-current feeders on the Edison system at 110-220 volts in business districts, and some installations of 220-440-volt mains have been made where it was desired to avoid primary lines.

Lighting is quite generally served single phase; while power service is given from two-phase or three-phase mains. Two-phase systems are in use chiefly where this method of distribution was established in the early period of development and is too extensive to warrant changing to the three-phase system. Three-phase systems are standard for all new installations where polyphase supply is desired for general power service.

Single-phase distribution is cheapest for lighting and small power mains at the load densities usually found outside of business districts, as the smallest size wire which should be used for mechanical strength is ample for ordinary loads. Three-phase, three-wire primary distribution is preferable in cities

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where substation loads do not exceed 1000 to 2000 kw., but four-wire distribution is most economical for larger loads and the greater distances which usually go with them in the large sizes. The four-wire system—being a 2300-4000-volt system—permits the supply of larger power users at outlying points more economically than by three-wire, 2300-volt systems.

The ability to regulate pressure independently on the different phases with greatly unbalanced loads makes possible the use of single-phase lighting distribution without sacrificing the advantage of three-phase transmission on the feeder.

The supply of power service in manufacturing districts is sometimes accomplished by the use of separate power feeders, the lighting being carried on other circuits. In other cases the light and power are combined. The use of separate power circuits tends to produce a duplicate distributing system and requires increased feeder capacity on account of the lower power factor, while with combined service the lighting tends to keep the power factor up. The diversity of demand between power and lighting loads also makes possible a considerable saving in feeder capacity where the lighting load in a given district is of the same order of magnitude as the power load.

Thus the policy of a combined feeder system is preferable from the standpoint of both feeder and main investment, in most cases.

With modern pressure regulating apparatus there are not many situations where the lighting service cannot be made what it should be, when power is served from the lighting system.

The primary main system cannot be interconnected as the mains in a low-tension system, because it is impracticable to provide fuse protection in such a way that it will isolate a section of main which is in trouble without simultaneously blowing other fuses through which the energy is supplied. Thus the primary system loses the advantage of parallel feeding, and requires that the feeder end be located as nearly as possible to the electrical center of the district which it serves. The arrangement which gives the best distribution of pressure thus naturally takes the form of a center of distribution with radial mains. These centers of distribution should be chosen so that the drop on the primary main will average about 2 per cent from feeder end to transformers. This limit is not always commercially feasible in the case of lines to outlying districts where the load is not yet large enough to justify the cost of extending a feeder.

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The usual form taken by a single-phase circuit laid out in this manner is shown in Fig. 7.

In cases where a feeder follows a main thoroughfare along which most of the load is located, and the side branches are short, the tree system sometimes is used. This tends to give high pressure at the near end and low pressure at the far end but saves the cost of a "back feed" main.

In three-phase, four-wire systems a modified form of the

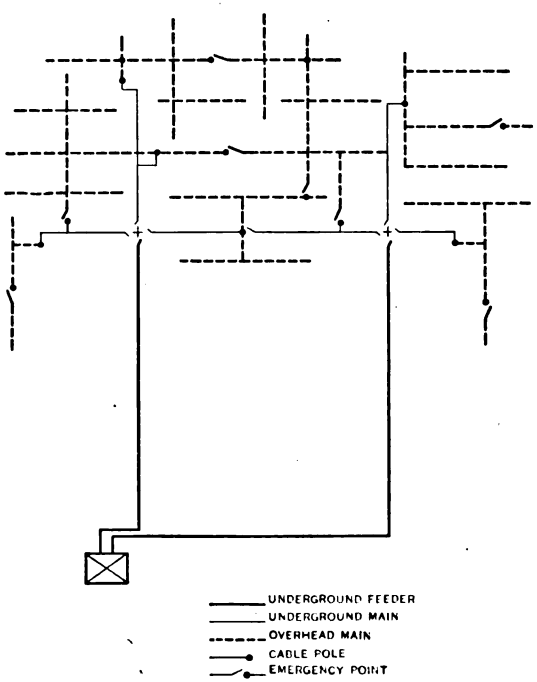


FIG. 7

center of distribution plan may be used, as shown in Fig. 8. The center of distribution of each phase is located with reference to the electrical center of the single-phase load carried by that phase. Since each phase can be regulated for pressure separately this gives a good distribution in scattered districts, and permits feeders to be loaded more heavily than is possible when the load is distributed from a single center. In the denser business districts it is possible to pick up enough load for a feeder within a small radius, and a single center is adequate.

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The separated centers of distribution can be used in two-phase systems but do not work out well for three-wire, three-phase circuits, since the line drop compensators cannot be set to take care of drop in the single-phase branch after it leaves the other phases.

### Emergency Switching Points

Where portions of the primary system are underground and where mains of adjacent feeders come together it is important that suitable facilities be provided by which the mains of the two circuits may be joined together in emergencies. Cable

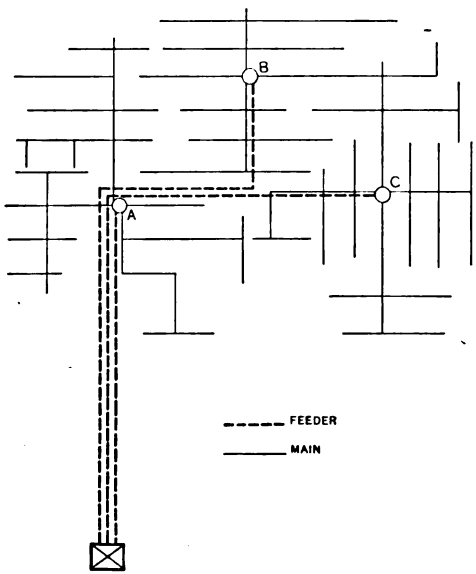


Fig. 8

repairs require a considerable time and if service is to be resumed promptly such emergency connections must be provided in sufficient number to permit the minimum interruption of service. Emergency switching points are also necessary as a means of putting sections of cable out of service while new cable taps are being cut in. The safety of linemen and continuity of service largely depend upon the facility with which sections of the primary main system may be controlled. Outdoor types of oil switches are used to some extent on important branches. The disconnecting type of porcelain pothead is found well adapted to this work, particularly at cable poles.

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An arrangement of two adjacent feeders with mixed underground and overhead lines provided with facilities for emergency switching appears in Fig. 7. In case of the failure of any section of cable main-service may be resumed as soon as a repair man can open the potheads on the cable poles connected to that main, and close the emergency connection separating the overhead branches from the adjoining circuit.

## Secondary Main Systems

The arrangement of secondary mains depends largely upon the density of the load. In outlying districts where the load runs from one to ten kilowatts in each block the size of secondary wires is comparatively small and the distances between transformers are such that the interconnection of adjacent secondary mains is not commonly considered desirable. The geographical arrangement of such mains tends to follow principal streets with few important mains intersecting. The failure of a transformer fuse under these conditions throws an overload on the adjacent transformers and the entire interconnected main is likely to be put out of service.

In the denser parts of a city where business buildings are served, a cross-connected network may be developed. This is less likely to cause trouble as the load of any transformer in trouble is usually divided between more than two transformers, and the danger of blowing other transformer fuses is lessened.

The secondary system may be protected against trouble originating in the transformer by the use of "network protectors." In New York City it is customary to operate the larger transformer secondaries in parallel, using such a device quite generally. The "network protector" consists of a small transformer having the same ratio as the main transformer. The primary and secondary leads of the main transformer are carried through the protector in series. In case of a defect in the transformer the fuses of the protector quickly open the connections to the network and thus prevent the current from blowing the fuses of other transformers.

The interconnection of secondary mains has the advantage of permitting the use of spare capacity, where available, to take overloads on adjacent transformers. The diversity factor between different groups of customers may thus be utilized to make a reduction of transformer investment in some cases.

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Motors cannot usually be served from lighting secondaries (except in the smaller sizes) without interfering with lighting service, on account of the fluctuations of pressure caused by starting currents. Where the requirements of lighting service are high it is therefore necessary to install separate transformers for power customers having motors of five h.p. and upward. In scattered residence districts it is often necessary to put motors of one h.p. and larger on separate transformers.

In alternating-current distribution in congested business districts where a network may be developed underground with loads of 75 kw. and upward in each block, it is very desirable to be able to serve light and power from one system except, perhaps, for users requiring about 26 h.p. and upward. The problem has been met in several instances by retaining the 500-volt direct-current distribution and establishing a three-wire Edison alternating-current network for the lighting and miscellaneous small power in the congested business portion of the city.

The secondary network of mains may be supported by transformers in vaults with primary feeders or by low-tension feeders from a centrally located substation. The primary feeder supply is the more usual as it follows the natural course of development.

As the load density increases the difficulties of getting ventilation and adequate space for the vaults multiply. The installation of a substation, centrally located, with alternating-current, low-tension feeders at the proper points, finally becomes the most economical and practical plan. About enough is saved in the cost of the vaults and transformers to offset the extra cost of feeders.

Where there is no direct-current power system provision must be made for alternating-current power service. In smaller cities this is provided for by separate transformers for the elevator service and for the larger general power. This permits the lighting to be served by single-phase, three-wire secondary mains.

In cities where lines are underground in the business district it is very desirable to be able to serve all customers from one set of mains as far as possible. This may be done by the use of four-wire, three-phase, 115-200-volt secondary mains supported by transformers and primary mains, or by low-tension feeders.

The proper distribution of lighting load between phases must

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be maintained in order to avoid the effects of unbalance. The odd voltages of this system are a bar to its adoption if any considerable number of 220-volt motors are already in service, or if the lamps are rated lower than 110 to 112 volts.

When the load rises above 150 kw. per block, the problems of carrying large volumes of alternating current in lead-sheathed cables multiply, and a condition is reached where direct-current distribution seems to be a practical necessity from the cable standpoint, and the importance of the service requires the protection of the storage battery.

### Transformer Selection

The determination of probable maximum demands of a user or group of users is of much importance in the selection of transformer sizes. Information based on experience and analysis of demands of different classes of users is necessary to avoid excessive investment in line transformers, as well as unnecessarily large core losses.

The systematic checking of transformer loads by the use of a suitable demand instrument is an important factor in keeping transformer investment within proper limits. This practise is followed by the larger central station companies quite generally. The practise of making contracts with large users on the basis of a demand measured by recording types of demand meters is of great assistance, as the maxima may be kept track of from month to month through the year and added load discovered as soon as it materially affects the demand.

The diversity factor between a group of consumers is so great in some cases that the demand of the group is very different from the demand of the individual users composing the group. The diversity factor is greater for residence consumers and similar classes whose use varies with their habits of living, than for commercial users whose requirements are fixed by more uniform conditions and whose demands individually are a larger proportion of their connected installation.

The following table represents average experience in the determination of demands of individual consumers and groups of consumers:

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TABLE OF MAXIMUM DEMAND FACTORS

| Classes of Users | Lighting Service Single | Group |
|---|---|---|
| Houses and Apartments | 55 per cent. | 20 per cent. |
| Offices | 72 " " | 60 " " |
| Small Stores | 75 " " | 60 " " |
| Hotels | 35 " " | .. |
| Churches | 50 " " | .. |
| Hospitals | 60 " " | .. |
| Manufacturing | 70 " " | .. |
| **Power Service** | | |
| Less than 5 h.p. | 86 " " | 70 " " |
| 6 to 10 h.p. | 66 " " | 62 " " |
| 11 to 20 h.p. | 65 " " | 63 " " |
| Over 20 to 50 h.p. | 53 " " | 45 " " |

The demand is given in this table as a percentage of the connected load.

The construction of alternating-current distributing lines for general service is very largely overhead. The use of underground work is necessarily limited to districts where the load density is such as to warrant the increased expense. In general, underground construction costs from three to five times as much as overhead work, where the load density is such as to require a 2200-volt main system.

Feeders and primary mains are sometimes placed underground on main thoroughfares, leaving the transformer secondaries and services overhead. This eliminates much of the risk incident to heavily loaded pole lines and avoids putting the more expensive part of the distribution underground.

The cost of distribution systems is materially increased by the necessity of doing the work piecemeal. The plant investment must be made with relation to the income which is likely to be derived within the period immediately following construction. The lines are therefore extended a block or two at a time, as the city grows, and the demand for service increases. The feeder system must be reinforced as may be necessary from time to time, to carry the added load. This involves re-arrangement of connections of primary mains and many complicated "cut-overs" which add to the expense very materially.

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## APPENDIX III. EFFECT OF CONSUMERS' APPARATUS AND WIRING ON DISTRIBUTION

BY H. GOODWIN

It is a comparatively simple matter to lay out a system of wiring a building, distribution lines and station apparatus which will give perfect service for any given combination of loads, but the duties of a distribution engineer are to make the best use of the lines available for supplying any proposed load without involving such cost as to make the proposition prohibitive from a commercial standpoint or without putting the consumer to such great expense for interior wiring as to make the service undesirable from his point of view.

When public electric service was first started it was for lighting purposes only. The service was generally only half night service; interruptions were frequent and voltage regulation was comparatively poor.

Conditions have changed and continuous good service has become in many cases a necessity.

### Motor Service

The use of current for lighting was soon followed by the use of current for motors. These motors were at first small, and on account of the general irregularity of service no great trouble was caused by them. The power business has since become very important. The multitude of uses for small motors has also contributed very largely to obtaining many consumers for lighting. Since the introduction of electric current for power and lighting have gone hand in hand, it is natural that often a single service has been run for supplying both the light and the power and the consumers' wiring has been simplified as much as possible by the combination of lighting and power loads without regard to interference with service to one by the other.

Since motors cannot be started without a greater demand from the lines than is necessary to run them after starting, various well known devices have been introduced to minimize the starting current.

Many electric power companies employ polyphase generation and both polyphase and single-phase distribution, the latter for lighting and small motors. In such cases it is necessary (in fairness to motor users as a whole and to the company) to have some fixed rule as to size of motor above which no single-phase service will be rendered and below which no polyphase

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service will be rendered. This size varies from 1 h.p. to 7.5 h.p. with different companies, depending upon local conditions.

The polyphase motor means a lower initial and a lower maintenance cost for the user; and for the power company it means lower and better balanced starting currents and less interference with lighting service of other customers, but on the other hand polyphase motors mean greater line and transformer expense (except in large sizes) and greater metering expense. Such a rule as to maximum size of single phase and minimum size of polyphase when once established in a community should be strictly adhered to in order to save money both for the company and for the small polyphase motor user when he moves from one street to another.

In order to cut down the starting current the general practise is to require auto starters on single-phase motors from two h.p. up and on polyphase motors of five h.p. and up.

Many central stations are apparently satisfied to accept an installation with an automatic starter while others require that the starting device shall limit the current to a certain number of times the running current. Elevator and hoist motors are sometimes allowed a higher starting current than motors for general factory uses.

Recently automatic self-contained starting devices for motors have been marketed and have several obvious advantages and prevent unnecessary blowing of fuses.

The objections are that there is no adjustment by which the starting current can be reduced for classes of service where the starting torque may not be as heavy as the average and for which the motor must be designed in order that it may be adaptable to all purposes.

The general requirements for elevator motors are that they must be of the wound-rotor type. The device for cutting out the resistance is often mechanical and independent of the current drawn from the line instead of being directly dependent upon this current. It is very generally of a dash pot type which in use wears and works more and more easily, so that the motor is ultimately thrown across the line before it has reached speed at all.

In order properly to limit the starting current of an elevator motor cutting out the rotor resistance should be controlled by a device dependent upon the reduction of the current in the feed wires.

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### Summary of Motor Situation

In this motor situation it might appear that the manufacturer's point of view is diametrically opposed to that of the central station. The manufacturer can sell more motors if they can be made cheaper, but all the devices which the central station desires to protect its lines from occasional excessive currents cost much more. However, a broad view would indicate that the electrical art and industry will develop most rapidly and permanently by assisting in keeping as low as reasonably possible the rates for electricity, which cannot be done if central stations are put to excessive expense on account of the poor characteristics of the apparatus used by consumers.

### Miscellaneous Apparatus

The question of allowing miscellaneous apparatus other than motors on lighting service still seems to be open and governed largely by local conditions. Rectifiers, cooking stoves, medical apparatus and the like are usually allowed on the lighting system except where their use makes trouble. Wireless apparatus is generally classed as the most undesirable on account of the high frequency going back over the lines and burning out meters. It is generally required that this apparatus be supplied from a separate transformer.

Various electric welding and riveting machines are in use. Where the primary lines have a capacity of above 100 kw. these welders or riveters when used singly do not seem to cause much disturbance.

### Consumers' Service Wiring

The effect of having to provide for the excessive current required for starting motors is that the consumer must wire for all apparatus other than lighting and above ½ h.p. an independent service.

The voltage of motors is also specified at 220 volts in order to minimize the starting current. Best practise now demands three-wire 110-220-volt distribution for single-phase service and it would also seem to require that all motors of one h.p. and above be made 220 volts.

The rulings in these matters are more positive for overhead a-c. distribution than for underground, on account of the large expense which would be necessary to introduce additional underground service. Best practise requires the load balanced on the three-wire service for loads above 24 lamps, although

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some companies will not run the three-wire service for loads below 40 lamps. The wiring for theaters and moving picture houses is subject to different rules in different cities. Emergency service is usually required in some form.

### Emergency Service

The necessity for emergency supply for industrial service is a matter on which there is much diversity of opinion. In general, some emergency supply is justified when the load factor and demand are large enough to bring the investment and operating costs below the average. Unusual restrictions are placed upon services for fire pumps by the underwriters, based apparently upon an assumption that electric service is not dependable in an emergency. Continuity of service is now so well established that it would seem to be time for a readjustment of these rules.

### Underground Service

The policy of introduction of underground service from underground lines by the central station company seems to be uniform. There, however, is still a divergence of opinion on the question of introduction of underground service from overhead lines. Some companies require lead-covered cable while others are satisfied with rubber-covered wire. However, the best practise would seem to be that the service be installed by the company. The expense must be borne by either party according to circumstances.

### Relation of Consumers' Apparatus to Charges for Service

It is proposed to consider the effect of consumers' apparatus on the charges for service. Rates are often based upon a charge for kilowatt-hours with a minimum charge and discounts for greater use. This minimum is usually based on the rated horse power connected to the service or on demand measurement.

The use of the Wright demand meter makes it an advantage to the consumer to have apparatus of high power factor, since the meter registers maximum amperes.

There is on the market a motor which gives unity power factor and thereby improves the general power factor of the system. Where such a motor is available arrangements could

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be made which would either reward the consumer for buying apparatus of good power factor or penalize him for buying apparatus of poor power factor.

It would seem to be well if some system could be worked out for basing the minimum charge on the starting current of a motor instead of on the horse power rating.

If a system of charges could be instituted which would penalize the motor with heavy starting current or exempt in some degree the motor with small starting current it would appear to be a great advantage to both the central station and the customer.

## APPENDIX IV. DIRECT-CURRENT DISTRIBUTION FOR SURFACE RAILWAYS—URBAN SERVICE

BY R. H. RICE

Electric railways very frequently have energy furnished to them over high-tension alternating-current transmission lines, and in this section of the report the substations are included in the distribution system. The component parts of the distribution system for urban street railway service are then:

1. The converting equipment in the substation;
2. The positive system from the substation switchboard to the car, including feeders and trolley wires;
3. The negative system, or returns, which complete the electric circuit from the car to the substation negative bus and include the electrical features of the track.

The usual city street railway system is characterized by having rather short feeding distances, large and rapidly fluctuating loads, and a wide variation in energy requirements at different hours of the day. Public demand is increasingly insistent upon quick and adequate service, better light and more heat, and this requires a greater amount of energy to be cared for in the distribution system, and greater reliability in its operation.

### Substation Equipment

Substation equipment has become quite standardized and various installations differ chiefly in arrangement and in minor details. The equipment in a modern substation is housed in a well-lighted and ventilated building constructed for this purpose. It should be so arranged as to leave ample space for making repairs, and for installing or removing parts as may be necessary. A traveling crane is usually provided to facilitate such

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changes, but is now frequently omitted as the standard modern machinery is so reliable that it is rarely necessary to make replacements of parts requiring the use of a crane. Not only is there a saving in the investment for a crane but the building may be made lower and the side walls somewhat lighter, thus making an additional saving. Frequently no heating plant is installed as the waste heat energy from the machines is sufficient to give a comfortable working temperature.

The supply of energy to a substation is almost universally from three-phase high-tension lines, and for railways is of 25 cycles. For city service such high-tension lines should be, and usually are, underground to ensure more reliable service and to prevent danger to the public by exposure to high voltage. Conversion to direct current in the substations is by the universally accepted machine, the synchronous converter. It is desirable to have a separate high-tension line to serve each converter when the machines are of large capacity, and used in important city service. Switching arrangements are made to use any converter with any incoming line, so while the normal operation on the alternating-current side is by independent units of high-tension line, transformers, converters and other apparatus, emergency connections may be made as desired to interconnect the units. On the direct-current side the converters are operated in paralled, being connected to common positive and negative buses.

The synchronous converters used for railway purposes are 600-volt direct-current, compound-wound, and the later machines have commutating poles. Just a few years ago a 2000-kw. unit was the limit in size, but 4000-kw. machines are now in service. The cost of these large machines is less per kilowatt and they occupy but little more space in the substation, making the area per kilowatt much less than formerly. It is possible to place a 4000-kw. machine on the same foundations formerly occupied by a 2000-kw. unit. Care in design has made this improvement possible, and the later machines contain numerous refinements in design which in the aggregate improve this class of machine very materially.

Switching is performed by motor- or solenoid-operated oil switches controlled from the main switchboard, and energized from a low-potential storage battery circuit. This battery circuit also provides current for the switchboard and station emergency lights.

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An effort is made to keep the power factor of each station unit as near 100 per cent as possible. The rotary shunt field and the reactance are so adjusted that with a given high-tension line voltage and direct-current voltage the converters will operate with 100 per cent power factor when fully loaded. If the converters are operated under overload conditions there will then be a leading power factor, and if operated under less than full load there will be a lagging power factor. Most railway substations can operate very near to 100 per cent, and this is usually desirable when energy is purchased from a central station company. In some cases a penalty is attached, in the way of increased power cost, when the power factor deviates from 100 per cent.*

### The Positive Feeder System

There is not much variation in practise among companies in positive feeder distribution. In general the trolley line is sectionalized by line breakers or section insulators, placed as desired, and each section is fed from a separate feeder panel in the substation. This feeder is very often composed of several cables running by different routes and tapping in at different points to a distributing cable running along the street, from which feed taps are made to the trolley wire. The above "radial" system of distribution is not so economical of copper as a "network" system in which all of the trolley wires form a continuous network and the feeders furnish energy to selected points of the network. As the load shifts from point to point all of the trolley wires and distributing cables act as equalizers and feed current to the point needed. It is difficult to locate trouble in an extensive network of this kind and also difficult to isolate the portion in which the trouble occurs, so that this method is not in common use. Some effort has been made to utilize the advantages of a network with the radial system by joining adjacent trolley sections through fuses or circuit breakers. Such a method has not been found satisfactory because it was impossible to adjust the connection so that it would distinguish between a heavy transfer of current from one section to another due to shift of load, which it should allow, and a heavy flow of current into a section due to short circuit, which it was not intended to permit. As a result these section connections

*See "Power Factor Control by Rotary Converters," Nicholas Stahl, *Electric Journal*, December, 1913.

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usually became so unreliable that they could not be depended upon and were abandoned. A common practise at present is to provide knife switches, mounted in a pole box, which are normally open, but which may be closed on each end of a section if for any reason the feeders to this section become disabled. Such a plan provides a quickly operative and convenient device for ensuring continuity of service, as it is quite unlikely that the two sections adjacent to a disabled section would also be out of service.

The feeders may be underground or overhead. In the largest cities, and in many of the smaller ones, the municipalities require underground distribution at least in the central business district. The underground cables are installed in tile ducts and at frequent intervals lateral connections are made between these cables and the trolley wire overhead. A typical lateral connection consists of a tile duct, or fibre-lined iron pipe, running from a manhole to an adjacent trolley pole, and connecting with a vertical fibre-lined pipe clamped to the pole. This vertical pipe should be at least 10 ft. (3.04 m.) high, and just above its upper end a switch box and lightning arrester are attached to the pole by means of brackets. The lateral underground cable is run from the manhole to and up the pole and connected to the switch. Between the top of the pipe and the switch the cable should be stripped of its lead sheath, taped and painted with an insulating paint, and the top of the pipe should be capped with a split wood plug which is cored to fit the size of the cable used in the lateral. This should be done to keep snow and rain out of the pipe.

The lightning arrester is attached to the riser from the switch-box and the ground wire passes down through the pipe to a ground rod in the floor of the manhole, or is attached to the rail. The mode of grounding the lightning arrester is a disputed point to some extent, but undoubtedly a good connection to moist earth is preferable to grounding to the rail. Running the ground wire through the lateral pipe may also cause some trouble, but this is frequently done, as no better method is usually available.

These laterals, although a relatively small part of the distribution system, may, if they are improperly insulated or installed, become the weak links which determine the strength of the whole distribution system. All cables should be rubber-insulated, the clamps holding the weatherproof riser to the pole

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should have an insulating band between them and the pole, and the cable should be held in the clamp by a split insulator. This gives three insulations between the conductor and the pole and will practically prevent "hot poles."

When the feeders are overhead the connection to the feed span is very simple, using either a jumper or making the span up with a tail. In this case lightning arresters are spaced along the line as local conditions demand, probably about five or six to the mile on an average.

The most commonly used trolley line construction is the standard span supported on tubular two- or three-section steel poles set at the curb line. The span wire almost universally used has been galvanized steel, but silicon bronze strand or copper-covered steel wire is now meeting with considerable favor. It has been found that steel strand frequently has very short life, especially in some manufacturing localities where atmospheric corrosion is especially pronounced, and other material resists such corrosion better than steel strand. The span should have two insulators cut into it between the trolley wire and the pole, and these with some form of insulating hanger for the trolley wire, give three insulations from wire to ground. Clinch ears are to be preferred to soldered ears and are more frequently used. The tendency is toward simplicity in construction, but with such means as will increase safety and reliability.

Overhead trolley special work is an important item in construction. There are many complicated layouts at busy corners, and reliability of construction is paramount. Often with long cars it is necessary to set poles considerably back of the curb line to secure proper clearance on curves, and sometimes the city authorities require that poles be set back to the building line at important corners. It is desirable to develop standard layouts which are designed with a minimum amount of overhead material, and in which the stresses are so balanced as to secure reasonable assurance of permanence in the structure. In such construction great care must be taken to align the trolley wire so that the trolley wheel can readily follow it without undue restraint.

In the 1913 report of the Power Distribution Committee of the American Electric Railway Engineering Association may be found specifications for material and construction of overhead trolley lines. In the various annual reports of the Board of Supervising Engineers of Chicago will be found the results

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of numerous tests on trolley material, such as poles and strain insulators, and also descriptions of special forms of construction. One of the most difficult things to secure is a good quality of trolley wire. High conductivity has been assumed as the chief criterion in securing a first quality wire and other desirable qualities have been sacrificed to secure this one. For a city system, with dense traffic, many feeders and frequent taps, the conductivity of the trolley wire is not of paramount importance. The qualities of toughness and high tensile strength are most important and it is desirable to place an upper limit on the conductivity and make the other requirements more severe than has usually been the case. The particular qualities required and the method of securing them in trolley wire is a subject worthy of considerable further study.

In any street railway system the load will fluctuate widely and it is a question of importance to determine upon what particular basis to design the feeder system. The load factor, that is, the ratio of the average load during the day to the maximum within the period, is usually from 40 to 50 per cent in an ordinary railway system. If the feeder system is designed to carry the peak loads without an overload on the cables, then during a large part of the day the current in the cables will be far below their safe carrying capacity and considerable copper will be idle. On the other hand, if the feeder system should be designed on a basis of say a six-hour average load, then the cables would be subjected to large overloads for a considerable period of time, heating would occur, the cables would more rapidly deteriorate, and a shorter life would result. The two-hour average is a good basis for feeder calculation as the ordinary percentage of load in excess of this value is well within the overload capacity of the cable, especially since this excess load lasts for such a brief time. If this basis is assumed it means that the feeders will carry the entire load without being overloaded, except during two-hour morning and evening peaks.

The detailed method for computing the feeders necessary for a city system has been fully described by the writer in a paper published in the *Journal of the Western Society of Engineers* of June 1910, and in the Second Annual Report of the Board of Supervising Engineers, Chicago. Briefly, the method is to determine from the proposed operating schedules the total number of cars required during the "rush hours," and plot them upon a skeleton map of the system, thus making a "spot

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map." The afternoon maximum period is usually the heaviest service period so that the car distribution for two hours of what is styled the "p. m. rush" is used on the map. On another map the trolley sections are indicated and the number of cars in each section determined from the spot map. This number of cars is then multiplied by the previously determined amperes per car, giving the current load for each section, which is placed at the center of load of that section. The required number of amperes per car should be determined in all cases by tests upon the particular equipment used and service demanded. This map is the "load distribution map" and shows very clearly the energy requirements of the system.

A study should then be made of the proper location of substations. The best probable locations and trolley sections for each station are selected and a graphical calculation of load center for each station is made by finding the combined center of gravity of the loads about each station. If the station locations chosen are not the most economical for distribution of copper, studies are made of comparative costs for other locations where the company may have property or where real estate may be obtained to advantage. After the station locations are definitely settled and shown upon this "station load center diagram" and the sections to be fed from each station are decided upon, light radial lines are drawn on the "load distribution map" from each station to the center of load of each section, which shows at a glance just what streets are fed from any given substation. Because of its appearance this modified "load distribution map" is known as the "spider diagram."

The most desirable routes for the cables are then determined, and the distance from the substation to the center of load of each section is measured on a large scale-map. After the computation of the cable necessary for each trolley section has been made a "feeder diagram" is prepared. This shows, by a properly selected code, from which substation each trolley section is fed, the number, size and route of all cables, and whether the cable is underground or overhead.

The calculation of the size of feeders to serve any given trolley section depends upon four elements:

1. The load in amperes upon the section.
2. The distance of the section from the station.
3. The allowable drop in the feeders.
4. The current-carrying capacity of the cables.

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It is desirable to limit the cables used to a few sizes only which may be kept in stock. The labor cost of replacing cables is practically independent of the size, and the larger sizes are thus more economical than the smaller. For underground cables the 1,000,000-circular mil size is a desirable maximum as it is readily installed in a standard 3 or 3½-in. (7.6 or 8.9-cm.) duct, in lengths convenient for handling. The current-carrying capacity of a cable does not increase as rapidly as its cross-section, because of the inability of the cable to radiate the heat developed. A great deal of study has been made upon the carrying capacity of cables but no very definite knowledge has been obtained, or at least made public, upon the safe capacity of cables of various sizes and kinds in ducts constructed in ordinary street soil. A carefully conducted series of tests, having this end in view, would be very desirable. In overhead lines the maximum size of cables is determined almost entirely by the weight of cable it is convenient to pull over the cross-arms and to handle upon the poles. Probably the most common size in city service is 500,000 circular mils.

The allowable drop in a feeder may be of any value desired and it is not usually fixed at the most economical value. For a city system subjected to large peak loads a small drop, even at peak loads, is desirable even though it is not economical with respect to feeder investment, because it is important to operate the car motors at approximately their rated voltage, and the public requires good illumination in the cars, which cannot be secured with a fluctuating voltage. A value of 10 per cent positive line drop under peak load conditions is not too good a standard to set as this means a 60-volt drop on the common 600-volt system. Even this is too large a drop to allow unless the negative return circuit is also designed for a small drop.

The load on the trolley section and the route of the cables has been determined as previously explained. It is only necessary to measure the feeding distance on a large-scale map and then the elements of the computation are all known. The first step is to select the size of cable necessary to carry the load, and then compute the drop. In general for those sections near the substation the cable size fixed by current-carrying capacity is the proper size to use, but for the more distant sections the voltage drop limitation may require an increase in cable size. To make such calculations readily a chart may be used in which are curved lines of constant product, and super-

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imposed upon these are radial lines showing the relation between distance and drop for various sizes of cables. Numerous other means have been devised for making the same calculations, but unless there is a great deal of computation to be done at one time special methods are not needed.

When a number of stations furnish energy to a city system, each station has a feeding district of its own and may operate independently of every other. But it is usually advisable to operate such stations in parallel so as to distribute the load and to have the benefit of assistance from other stations adjacent if any one is partially or wholly disabled.

Theoretically, the best manner of accomplishing this is to provide direct equalizing ties between the positive buses of the stations just as machines are equalized in a station. The objection to this is the large cost of the cable which is necessary, and which is not utilized directly in furnishing current to the cars. Essentially the same result may be accomplished by feeding a number of the more important trolley sections from two separate substations in such a way that in case of the shut-down of one station or of accident to one feeder, the cars on these sections could still be operated from the second station. These are designated as "tie-sections," and in addition to the above advantages, the feeders are so proportioned and calculated that on the whole system in case of the shut-down of one or two stations, the cars on the more important sections can be operated from the remaining stations by interconnecting through these tie sections. The amount of energy drawn over these tie lines is regulated both by the relative resistance of the cables and by voltage control in the stations. This tie line system represents in a measure the factor of safety necessary for successful operation. The number of such lines varies with the importance of the stations and the density of traffic on the individual sections fed from them.

## The Return System

The design of any overhead trolley system naturally involves provision for as direct a return of current as possible to the negative station busbar. Practically all city railway systems use grounded return circuits, the negative side of the distribution system being connected to ground. Although utilizing the full carrying capacity of the track rails insures that the majority of the return current will follow this path, a certain

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proportion may reach other metallic underground structures which happen to offer another return path to the locality of the substations. It is very desirable to limit these "stray currents" to a small value in order to reduce the possibility of electrolytic damage to a minimum. Another decided advantage in making the return circuit very good is of course to reduce the energy losses. It is too often the case that the return circuits, except possibly for rail bonding, are almost wholly neglected, while the positive system is carefully planned and constructed. A poorly built negative system does not jeopardize life or cause delays to the same extent as similar neglect in the positive system would do, but elements of danger and loss are present which should under no circumstances be neglected. Negative feeders are unlike positives in that the cables form a network all connected to the tracks, instead of a group of independent cables running to unconnected portions of the trolley wires. The earliest form of return circuit was the rails only, which were bonded at the joints, and later a connection was made at the power station between the rails and the negative bus. As the loads and distances increased the drop became excessive on these simple track circuits, and supplementary conductors were provided to reduce the drops. The simplest method of doing this is to provide return conductors in parallel with the rails, and in such sizes as to reduce the return drop to the required amount. As approach is made to the substation the current increases, due to the accumulated load, and in order to keep the return circuit from being overloaded the supplementary conductors must be increased more and more the nearer the approach to the power station. The amount of such supplementary copper necessary is computed from the allowable maximum return drop.

It is difficult to make a calculation for this supplementary copper in the case of a city system whose tracks form a complicated network of conductors. But it can be done by assuming the load distribution as in the positive feeder calculations and applying Kirchoff's laws to each element of the network formed by the intersecting tracks. The track lengths, conductivity, and loading being known the drops may be found. If the drops must be reduced, this may be done by reinforcing the track circuits by additional copper.

In a grounded system, using the rails and supplementary copper for returns, in order to secure the full benefit of the sup-

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plementary copper it is necessary to connect the tracks frequently to this copper. This bond serves as an equalizer between tracks and enables the full track and cable conductivity to be utilized when the load is all on one track as well as when evenly distributed. The supplementary copper should be run through all special work and directly to the negative busbar. Where two cables cross, as at intersections, they should be electrically connected so that their equalizing effect may be realized. All rails on straight track should be at least well bonded, and preferably welded, so as to make the joint as good a conductor as the stock rail. At track special work, such as intersections, curves or crossovers, it is not usually feasible to weld at the rail joints and the special work may thus be cut off from good electrical connection with the tangent track. To preserve the conductivity of the track circuit, special work cables are run through the special work and welded to the tangent track at each end. The value of the return circuit thus does not depend upon the special work rails, which may be removed without materially affecting the conductivity. Further details of such a system, and the results of tests on cable and bond terminals used as outlined above, may be found in the Third Annual Report of the Board of Supervising Engineers, Chicago, 1909.

The "insulated return system" is another method of constructing a railway return circuit. In this the return current is taken from the track circuit at various points, selected so as to maintain the track drop within any desired limits. The drop on the insulated cables may be of any amount up to the value which will cause the current to equal the carrying capacity of the cable, and the drop may or may not be of the same value on all the cables. The tendency will be for the shorter cables near the substation to become over-loaded and sometimes a resistance must be inserted in these cables to limit the current and make the drop approximately equal to that on the other cables. It is possible to use negative boosters with these insulated returns but they add much to the operating difficulties, and have found no favor in this country. The insulated return system has been used much more extensively in European countries than here. Two papers* bearing especially upon this subject have been presented by Messrs. J. G. and R. G. Cunliffe and appear in the *Journal* of the Institution of Electrical Engineers.

* "Electric Traction Vagabond Currents," Vol. 43, Part 197 (1909), and "Tramway Feeding Networks," Vol. 50, Part 219 (1913).

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Numerous matters of interest have not been touched upon in this report, but an attempt has been made to cover the fundamentals and to record good modern practise. Some important matters of design, such as the most economical number of substations, their location, and the maximum economical feeding distance, have not been discussed. Other matters of less theoretical character offer equal opportunities for investigation—such as the possibility of using higher voltage in operation, and the use of some form of three-wire system.

## APPENDIX V. DIRECT-CURRENT DISTRIBUTION FOR UNDERGROUND AND ELEVATED RAILWAYS

BY E. J. BLAIR

The term "underground and elevated railways" used in the title of this report refers only to such railways when used for passenger service in large urban centers. The word subways may be substituted for "underground railways" to make the meaning more clear.

The railways of this description at present in operation or under construction in the United States distribute direct-current energy at approximately 600 volts bus pressure, using in general a third rail for the working positive conductor and the track rails reinforced by other conductors for the return circuit. Therefore this type will be given specific attention, although before passing to the details, mention will be made of other methods of distribution.

With the same type of distribution there is of course the possibility of increasing the potential. This would not seem desirable, thereby causing a departure from the established equipment standards, because for subways and elevated roads the density of loading will always be rather heavy on account of the class of service. This necessitates numerous distributing points, and on the other hand the length of feeding will never be very long, so that 600 volts bus pressure can be accepted as good practise and the advantage of higher pressure would not offset the disadvantages. For the same reasons, no time will be spent in discussing the matter of alternating current.

Passing to other types of direct-current distribution, several modifications of a three-wire system are used in different parts of Europe. The most radical of these is the method used in the subway of the City and South London Railroad, which is a

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double track tube using the third, rail conductors of the two tracks as the outside wires of the circuit and the running rail as the middle or neutral wire. This of course has the effect of minimizing the current flow in the track rail and thereby eliminating trouble from stray currents. However, such a method is only possible with a small and simple system, wherein the current loads are practically balanced between the two tracks. Another similar method is that used in the Nord-Sud subway in Paris, where a third rail is used for one side of the circuit and an overhead trolley wire for the other side with 1200 volts between the two and 600 volts from either to the track rail. This method would seem to be preferable to that of the City and South London, since it is not necessary to balance one track against the other. It also is used for the purpose of eliminating stray currents from the grounded track rail, by reducing the current in the track rail.

In London in most of the subways and tubes a fourth rail is used for the negative conductor, placed on the opposite side of the track from the third rail or more generally in the center of the track. This scheme of course entirely eliminates the difficulties from stray currents from a grounded track rail, since both sides of the circuit are insulated. It introduces operating difficulties due to the addition of the fourth rail, especially when one side of the circuit becomes grounded, as sometimes the results react upon equipment at distant parts of the line. It also adds to the burdens of maintenance, and complicates construction, especially at cross-overs and switches. Such a system is quite necessary in London on account of the severe limitations of return circuit drop imposed by the British Board of Trade when grounded conductors are used. With ordinary care the drop in track rail return circuits in the class of service under discussion may be kept within such bounds as will not cause electrolytic damage and therefore to resort to the fourth rail would not seem necessary unless municipal regulations exact it or unless for any given condition good engineering economy justifies it. However, in laying out a new system it would always be well to carefully weigh the merits and costs of the fourth rail system against the method of track rail return with its necessary auxiliary copper.

The type of construction common in the United States, namely the third rail with track rail return, is the particular object of study of this paper, since it is most common and more

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nearly meets all conditions. Where traffic is so dense as to require the construction of an expensive subway or elevated railroad, then the distribution must be laid out in such a way as to fulfill the following conditions, namely:

a. The maximum of reliability.

b. Ability to care for peak loads out of all proportion to mean requirements.

c. Heavy currents per train unit, and such close headway that extreme current densities obtain per mile of track.

In laying out such a system, therefore, the problems of size and amount of conductors, etc., are the least difficult for the engineer to solve, and the most important feature to be considered is that of simplicity and perfection of operation. The tendency has been to lay too much stress on the former and not enough on the latter. The methods of computation for feeder sizes, etc., described in that portion of the report given over to surface cars systems, may be applied to some extent to calculations for elevated and subway work. In considering the operating features we find that the arrangement and division of the electrical distribution with respect to the track, or what is called sectionalizing, is worthy of the most careful attention.

An elevated or underground railway is, generally speaking, not composed of the complicated network of tracks and line distribution that is found on a surface car system in a large city. In other words, the current is distributed from substations or power stations in a straight line on both sides of the station, whereas for surface car systems the distribution radiates in all directions from substations. The fact that we have no networks to consider makes positive and negative distribution a much more simple task from the purely electrical engineering view point, than is the case on surface roads. There seems to have been a tendency, however, to follow their precedents originally in methods of sectionalization, especially as to the matter of connecting both tracks of a double-track road to the same electrical section. This scheme may have its advantages in economy of distribution, but its great disadvantages from an operating point of view more than outweigh such advantage. In effect it makes a single-track railway out of what should be a double-track road.

Investigation has been made of several properties, each having different methods of sectionalization and all of them fairly typical of conditions throughout the country. One of the

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methods is that described above, namely, both tracks being tied together. In another case a large part of the railroad is connected on one common system of feeders and switches every few thousand feet along the track are employed for isolating parts that are in trouble. This system is even more difficult to operate than the other. Still another system, and the best of the three, separates the two tracks from each other and also breaks the system up longitudinally at intervals. This latter system employs practically no track switches and therefore puts all section circuit breakers and switches on the switchboard in the power house or substation.

The diagrams shown in Fig. 9 typify these three systems of

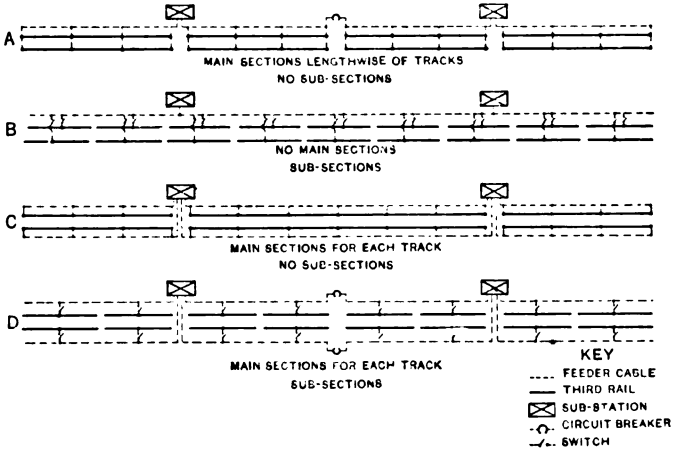


FIG. 9

sectionalizing, with a fourth that is more nearly the ideal one. In each diagram a double track road with no branches and with two substations is used to illustrate.

Fig. 9A is the system with the two tracks connected together on the same feeder cables and hence on the same circuit breaker or breakers in the substation. It is divided lengthwise at points opposite the substations and at a point half way between the two. At this latter location switches or circuit breakers are installed. Thus there are four sections shown. Of course in many instances there may be additional sections on the ends with independent feeders. This system uses the conductivity to good advantage, but it is at once apparent that a short cir-

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cuit either of momentary or prolonged duration on either track affects the other track and causes operation in both directions to cease.

Fig. 9B shows both substations feeding in on a common bus, that is, all feeder cables and conductor rails are connected in one general section. This also is very economical of copper but usually necessitates several circuit breakers being in parallel on the distributing board, a condition which in itself is undesirable. To give an opportunity to isolate trouble either track switches or track circuit breakers are installed at intervals of a few thousand feet. The track circuit breakers to be effective quickly, both on opening and closing, should be controlled from the substation. In either event, whether they are remote control or simple circuit breakers, a large amount of maintenance is entailed on account of the number involved, and the fact that they are not under the eye of an attendant. It has been found desirable on one road to eliminate the automatic circuit breakers and rely on switches only. Even with the circuit breakers, a heavy short circuit is apt to open the entire section at the substation. With such circuit breakers of the ordinary simple type it is also quite likely that one may open and leave its particular sub-section dead until such time as some one closes it, which usually involves a little delay. All things considered, it is felt that such a layout is even less desirable than that shown in Fig. 9A, since there is no sectionalization directly under the control of a skilled attendant, unless the remote control feature with its complications is resorted to.

In Fig. 9c the tracks are separated from one another and each track is sectionalized longitudinally opposite the substation. Additional division may be had at as many points as may be desired along the track, necessitating additional feeder cables and panels. However, the substations will usually be sufficiently near together to do away with the necessity for this additional division. It will be noted that the sections between the two substations are common to both or are "tie sections." This may be done either solidly or through switches or circuit breakers. This method is not as economical of copper as that of Figs. 9A or 9B, but is very satisfactory from an operating point of view. The only bad feature is the two substations feeding into the common sections, making it necessary to get both ends open in case of trouble. It has sometimes been found advisable, in order to secure better economy of distribution,

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to connect the two tracks together through equalizing circuit breakers. This, however, adds another complication when quick opening is desired. In general a system of this sort operates very satisfactorily.

Fig. 9D differs very little from the scheme shown in Fig. 9C and is the ideal to be worked toward. The "tie sections" are connected through circuit breakers preferably remotely controlled by one of the substation operators, or, if at a convenient location to interlocking tower or dispatcher's office, by the attendant at such places. Sometimes the use of a circuit breaker with a no-voltage release is all that is necessary. It may seem that "tie sections" are not necessary, but in actual practise they are very desirable, since they permit of the shutting down of certain substations during very light load hours, and in addition they permit continuous operation of the road in case of accident to machinery in any one substation.

Such a system may be amplified by the addition of track switches or even circuit breakers where sub-sections are desired. It is believed, however, that good results will be obtained without either and that the switches without the circuit breakers will usually be all that is necessary. With the system shown in Fig. 9D in mind, it will be well to go into one or two general considerations. First; how big should such sections be? This of course will depend upon several factors, the first of which is the geographical layout of the railroad. This consideration has its effect on the location of substations and the consequent distance between them. Extremely large substations for elevated and subway work should be avoided and consequently this means numerous substations. This belief is founded more particularly on return circuit conditions than on positive conditions. For a substation feeding two tracks and in two directions only, it would seem undesirable to go much higher than 5000 kw. in capacity. Where the feed is in four or six directions, as may readily occur at junction points, the capacity should not exceed 10,000 kw. This statement of course does not necessarily apply to what are called joint substations where different classes of surface and elevated or subway loads are handled. Assuming a single line of double track road served by 5000-kw. substations, it will readily be seen that in heavy elevated or subway service such stations will not be so far apart as to make "tie sections" very long. On the extreme ends of such systems single sections (not tie) should not be permitted

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to exceed two miles (3.2 km.) in length. This would mean a maximum of four miles (6.4 km.) for "tie sections." Of course with the usual elevated and subway service the sections would be of much less extent, if the size of substations were restricted to 5000 kw. The other restriction on the size of sections is of course that of load. Each section should be served by only one circuit breaker per switchboard to give the best results and it is not desirable in railway service to run circuit breaker sizes much above 4000 amperes, and 3000 is better. The former size will permit of an overload setting of 8000 amperes which should be ample for any one section.

To summarize, the single sections should be restricted in size to a mean load during heavy periods of 4000 amperes and to a maximum length of two miles.

With sections limited as above, track switches or track circuit breakers would be necessary only when isolation of short pieces of track is required. In subways this feature adds somewhat to the factor of safety to the public, and is even further carried out by providing means so that any motorman or other employee can instantaneously cut off the power by pulling a nearby box or cord. Certain municipalities require sub-division into very short lengths in order fully to protect the public.

In dividing a railroad up into sections, due regard must be given to the point of separation of sections. In general the opening between two sections should not be closed by a car in passing over same. That is to say, one collector shoe must not be on one section while the other shoe is on the adjacent section. With certain types of equipment when trains are "bus-coupled" it is impossible to avoid this. Where gaps between sections are apt to be "bridged" or closed by a car or a train, it is quite essential to keep the voltage the same on either side of the gap. It is desirable so to locate the gaps between sections that they will occur at points where motormen are normally not drawing power. A little care in the selection of gap points will materially improve operation of the car equipment. It is needless to say that from this point of view as few gaps as possible are desirable. In sectionalizing too much emphasis cannot be placed on simplicity in the switching arrangements, since this makes for speed in handling emergencies.

Complicated track junctions can best be handled as individual sections from the substation. There is always a tower at such places which affords an opportunity to further subdivide the

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junction through circuit breakers, so that in case of trouble at any given point, the towerman can immediately isolate it. This is of course carrying out the track switch idea to a certain extent.

### Construction Methods and Materials

Briefly stated, it is not good practise to use third rail conductors that are too light in weight, since they are much more difficult to maintain in substantial fashion. Further, it is not good to have third rails that are not reinforced by auxiliary copper. There is a temptation to run up the weight and conductivity of the third rail and not add the copper on certain outlying sections. In such cases where breaks in the bonds around third rail joints occur, it will be seen that without the copper to carry the current, a part of a section may become absolutely dead. So that even if for regulation no auxiliary copper is required, it is a good thing from the emergency side, and even a small copper conductor will be worth while to insure reliability. If such a thing is not used an emergency switch to cut in and obtain a back feed from another section is many times quite worth while.

One of the distinct advantages to be obtained from a system such as Fig. 9c which does not use track switches is, that all the conductivity of the third rail is brought into play as part of the feeder system.

Substation construction for elevated and subway service is almost identical with that for city surface car lines. This has been covered in that part of the report dealing with the latter type of railways.

### Return Circuits

This subject is such an important one that it hardly seems advisable to attempt to treat it as part of a general paper on distribution. Furthermore, it seems probable that more definite conclusions on the subject will be arrived at shortly than have been existent before, on account of the combined efforts of the various engineering associations. Suffice it to say that with grounded conductors such as are used in most of the present systems, great care must be used to keep within proper bounds the potential differences along such conductors. This is what makes it essential to resort to small and numerous substations. In most cases it is not necessary to insulate the negative conductors, but with grounded conductors one good way to limit the drop is by the use of insulated negative feeders.

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Such an installation has a more direct application and is more necessary in subway work than on elevated lines. Certain it is that not enough attention has been paid to the negative circuit in past installations.

## APPENDIX VI. DIRECT-CURRENT DISTRIBUTION FOR INTERURBAN AND STEAM RAILROADS

BY W. G. CARLTON

Prior to 1906, practically all direct-current operation on interurban or steam railroads in the United States was at potentials of approximately 600 volts. In general, power was distributed through an ordinary overhead trolley wire, this being reinforced by such additional feeders as were necessary. In a few cases power was distributed through third rails, the arrangement of third rail being practically the same as used on elevated and subway lines in the large cities. There was no electric operation of heavy trains on any of the steam railroads with the exception of the Baltimore & Ohio Railroad, at Baltimore, which operated trains through a tunnel at slow speed and for a short distance.

In 1906 the New York Central & Hudson River Railroad and the Long Island Railroad began changing over from steam to electric service in and near New York City. The Pennsylvania Railroad began electric operation through its tunnels in New York City in 1910 and about the same time the Michigan Central Railroad began electric operation through its Detroit River Tunnel. In all of these cases power was distributed over third rails at approximately 650 volts.

The New York Central and Michigan Central Railroads used a suspended type of third rail, contact being made on the bottom, the rail weighing 70 lb. per yard. (28.5 kg. per m.) The Long Island Railroad used a top contact third rail, weighing 100 lb. per yard. (40.8 kg. per m.) The Pennsylvania Railroad also used a top contact third rail, but weighing 150 lb. per yard (61.2 kg. per m.). Where necessary, additional feeders were used to reinforce the third rail and in some cases, remote control switching stations were installed for the purpose of connecting parallel third rails and cables and still being able to disconnect them quickly in case of trouble. With the roads mentioned, power was distributed from substations located from four to eight miles apart.

Railroads using the third rail method of distribution have

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found it necessary for locomotive service to install a small amount of overhead third rail or trolley wire over long crossovers. This overhead conductor is not necessary where trains of motor cars are used, as they will span the gaps in third rails at crossovers.

The substation equipment for 600-volt service has not changed materially for several years with the exception of the introduction of commutating pole synchronous converters and generators and the use of larger machines. Storage batteries are not being installed to any great extent, and for protection against interruption to service, ample capacity in substation apparatus and in high-tension lines between generating stations and substations is relied upon.

It is not probable that potentials as low as 600 volts will be used for electrification of steam railroads, with the possible exception of those in and near large cities. At the present time the tendency is towards the use of 1200 volts or higher, not only for steam railroads but for interurban roads of considerable length. There are in the United States, 28 railroads operating or preparing to operate at 1200 volts or higher, the maximum voltage being 2400. For all of these roads, the distribution is by means of an overhead trolley, although one of them is using third rail for a portion of its work and a second road is preparing to do so. In general, the catenary type of trolley construction is used.

Power for operation at 1200 volts is furnished direct from steam-driven generators in a few cases, but as a rule is furnished from synchronous converters or motor-generators, these being either 1200-volt machines or two 600-volt machines in series. The only direct-current 2400-volt road in operation at the present time uses motor-generators with two 1200-volt machines in series.

The Butte and Anaconda Railroad installation is an example of what can be done in handling steam railroad service. Direct current at 2400 volts is used. The trolley wire is No. 4/0 and but two feeders are needed, a 1,000,000-cir. mil for the positive side and a No. 4/0 for the negative side of the circuit. There are two substations 26 miles (41.8 km.) apart. In one direction trailing loads of 3400 tons are hauled, the maximum grade being 0.3 per cent. In the other direction trailing loads of 1000 tons are hauled, the maximum grade being 1.0 per cent.

The general problems of d-c. distribution for interurban

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and steam railway purposes are here omitted because, except for the weight of train units and consequent details of construction, they are not essentially different from those discussed by Messrs. Gear, Torchio, Rice and Blair, respectively, in earlier appendixes of this report.

## APPENDIX VII. A-C. DISTRIBUTION FOR INTERURBAN AND STEAM RAILROADS

BY W. S. MURRAY

In a number of instances attempts have been made to connect cities using direct current on their overhead systems by interurban lines using alternating current on their overhead systems. This necessitated great complexity in the design and control of the motive power equipment to perform the duplex operation. The attempt naturally did not meet with success as it was clearly an abuse of the application of alternating current. It may, therefore, be said:

That the alternating-current contact wire in general has no application in the interurban field where the equipment must be common to city and interurban operation.

Economies in steam railroad electrification may be looked for and secured by providing a high over-all efficiency from the terminal of the primary transmission system to the drawbars of the trains. Such a system is the one delivering high-voltage alternating current from a single overhead wire, which while doing this also possesses the greatest adaptability and elasticity under the onerous conditions imposed upon it by modern heavy transportation.

By reason of the general acceptance and standardization of 25 cycles, such a frequency in a single high-voltage contact wire, while conforming to a periodicity generally in use, also permits all classes of equipment to operate beneath it, such, for instance, as single-phase, split-phase and, through the medium of a rectifier, direct-current motive power apparatus. Therefore, in the case of steam railroad electrifications, in virtue of the above-mentioned facts, it would seem reasonable to offer as recommended practise the use of a single overhead wire furnishing high-voltage alternating current of 25 cycles as the contact system for the motive power apparatus operated thereunder.

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## APPENDIX VIII. THE RELATION OF DISTRIBUTION PROBLEMS AND SWITCHING APPARATUS

BY E. B. MERRIAM

The principal problems in the distribution of electric power which are affected by switching and auxiliary apparatus may be classified as follows:

1. Maintenance of continuous service supply.
2. Protection against service interruptions due to faults in the distributing system and receiving apparatus.
3. Safe interruption of circuits abnormally loaded.
4. "Safety first" protection for all who come near the distribution system.
5. Operation of the distribution system at maximum efficiency.

### Service Maintenance

The maintenance of continuous service supply is usually accomplished by feeding the distribution system from one of several sources of power supply through two or more buses or their equivalent. Connection is ordinarily made between the different parts of such a system by some form of switch in addition to a circuit-interrupting device.

For 250-volt three-wire Edison direct-current systems the switches are usually single-pole, single-throw, edgewise type. They are designed to be arranged in very compact form and economize space so that a large number of feeders may be controlled from a minimum size switchboard. For alternating-current and direct-current switching service at pressures up to 750 volts, it is customary to use the so-called knife blade or lever switch, mounted preferably upon slate and equipped with or without quick break features.

Alternating-current systems operating at pressures above 750 volts are equipped with plain lever switches furnished with detachable handles and usually some form of locking device for retaining the blade in the closed position against the action of large magnetic forces which are often developed during short-circuit conditions. Up to 2500 volts, these switches may be mounted on marble bases, but above this pressure the best practise demands that the switches be mounted on porcelain insulators secured to iron or steel bases, and located remote from the switchboard.

For direct-current systems above 750 volts, remotely controlled lever switches are becoming standardized. These are

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usually mounted on porcelain bushings set in slate bases forming part of the switchboard panels.

In some cases, particularly in isolated plants, automatic devices are sometimes installed to connect the house service system with the central station distribution system in case of failure of the isolated plant supply, but such devices have only a limited application.

## Service Protection

A means of giving complete protection against service interruptions due to faults which develop in the distribution system and receiving apparatus is now being diligently sought by manufacturers and operators. Their investigations have resulted in the development of numerous schemes for indicating the appearance of faults in the distribution system and for disconnecting faulty feeders without disturbing the healthy ones.

One of the indicating schemes depends for its operation on the unbalancing of the currents in the legs of a three-phase feeder caused by a ground or other fault. The unbalancing induces currents in special series transformers connected to the feeder and gives a visual and audible indication of trouble by tripping a shutter covering the number of the faulty feeder and ringing a bell.

Another scheme, originally developed abroad as a result of suggestions by Kallman and Andrews, depends for its operation on a difference appearing between the current entering at the supply end of the feeder and that leaving it at the receiving end when a fault develops. Until recently, it had not been considered for use in the United States because it requires the use of auxiliary wires to connect the devices placed at the ends of the feeders, and in some designs, special current transformers which may be balanced one against the other. Besides, under some conditions, it gives no indication of failure of continuity of the auxiliary circuit, which thus renders the protective feature inoperative. It is very sensitive, however, and discriminates accurately between healthy and faulty feeders. It can also be so adjusted that it will disconnect a faulty feeder before the fault gives rise to dangerous circuit conditions.

A modification of the above, which eliminates the auxiliary wires, has recently been developed. This divides each feeder into two parts, placing the parts in the same or in separate

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cables. The incoming and outgoing currents at the ends of the two parts of the feeder are then balanced through series transformers connected to them, and the secondary circuit arranged as before.

A number of other schemes have been proposed and are in operation, which depend on various kinds of overload, reverse-power and kindred types of relays. The overload relays are usually made partially selective by some form of time delay whose value is in whole or part a function of the overload current. Three principal types of time delay schemes are now available. One depends on the retardation effected by an electrically driven gear train, the electric feature being actuated by the overload current. Another depends for its time delay on the action of a permanent magnet on a disk of conducting material rotated between its poles. A third depends upon the retardation effected by the expulsion of air from a bellows through a fixed orifice.

The reverse-power relays depend primarily on a reversal in the direction of power flow. Numerous forms have been developed in which the solenoid, dynamometer, and induction principles have been employed with more or less success. They all depend on the interaction between current and pressure coils and their range is usually limited by the high minimum pressure at which they will operate without requiring excessive current flow.

### Circuit Interrupters

The safe interruption of circuits abnormally loaded presents one of the most difficult problems encountered in distribution.

For direct-current circuits up to and including 1200 volts the carbon-break circuit breaker is applied almost universally with eminent success. Above 1200 volts, however, it has been found necessary to adopt some form of magnetic blowout, and reliable circuit breakers utilizing this principle have been developed for direct-current circuits up to 5000 volts.

For all alternating-current circuits, with but few exceptions, the oil-immersed circuit breaker is now considered standard. It has been the object of considerable study and research, with the result that its operating characteristics have been markedly improved. The design of contacts, characteristics and quality of the oil, and shape, ventilation and fastenings of the oil vessel have been given especial attention. Further

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improvements may be looked for in the direction of increased speed of break, better confinement of the oil in the neighborhood of the arc, and an increase in the number of breaks in series per phase.

The duty demanded of oil circuit breakers has, however, been very rapidly increased of late due to the huge generating capacities now being concentrated in single units, and grouped in central stations. The stored energy of such systems has now become so great, that it is no longer possible for the oil circuit breaker to dissipate it unaided. Various schemes have therefore been proposed and adopted for assisting in the dissipation of this energy. The first one places reactance in the generator or feeder circuits so as to limit the power which could be obtained on short circuit. This reduced the drain on the generating equipment and in turn reduced the effect of the abnormal disturbance on feeders other than the faulty one. Another scheme introduces reactance into the circuit to be interrupted after the abnormal disturbance has been manifested and before the oil circuit breaker clears the circuit. This scheme reduces the current that the oil circuit breaker must interrupt but does not limit the initial drain on the generating system or protect feeders adjacent to the faulty one. A third scheme introduces resistance into the circuit in shunt with the oil circuit breaker during its operation. This scheme is the only one which increases the energy dissipating capacity of the modified circuit breaker and appears to represent the most efficient solution of the problem.

### Safety First

The protection of attendants and others from injury caused by contact or otherwise with distribution systems is being daily given more attention. To meet this situation, manufacturers have placed on the market lines of so-called "safety first" apparatus. It has all of the live parts enclosed in iron or steel compartments to which entry is prevented, except when the circuits leading in have been disconnected from the distribution system. These lines include all forms of switching devices from low-pressure, small capacity, single pole, single throw, fused lever switches to complete switchboards, for use on 15,000-volt high-capacity circuits.

### Operation Efficiency

The operation of distribution systems at a maximum efficiency requires a minimum investment in feeders and depends

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for its accomplishment, among other things, on the ability of the various switching and auxiliary devices properly to perform their functions. These devices together with their limitations have been discussed elsewhere in this report and repetition here is deemed unnecessary.

### Conclusions

It is seen, therefore, that a considerable number of important distribution problems depend for their solution on the characteristics and performance of switching and auxiliary apparatus and that strenuous efforts are being made to improve the various devices so that they will satisfactorily perform all their functions.

## APPENDIX IX. DISTRIBUTION FOR STREET LIGHTING SERVICE

BY PAUL M. LINCOLN

The problem of distributing power for the specific service of street lighting is quite different from that of power distribution for commercial lighting and other purposes. There are two peculiarities which differentiate it particularly from the usual distribution problem. These are:

1. That the area over which the power for street lighting must be distributed, must, at the same time, be served by an entirely separate general distributing system.

2. That all of the power for street lighting service must be switched at certain predetermined periods of the day, being needed only in the hours of darkness.

The fact that street lighting is required only at night makes it desirable that this particular service shall be fed by a separate distributing system, so that the power for use thereon may be turned on and off at will from a single point.

The alternative to the separate street lighting distributing system is to use the same distributing system for street lighting as for other purposes and to have the street lamps switched off and on singly or in groups at a point near the location of the lamps. This latter alternative presents so many difficulties that it has been used only to a very limited extent, where groups of lamps are located in a small area such as a small park or playground. Where lines are all underground it is usually cheaper to give this service from the general network and switch it at various points by hand than to build separate circuits.

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The requirement for the simultaneous lighting and extinguishing of all street lamps led to the development and continued use of the so-called "series system." In this system, all of the lamps of a given circuit are operated in series at a constant current. The amount of current used varies with the type of lamp, from a minimum of about four amperes, with some of the more recent types of lamps, to a maximum of approximately ten amperes, which was the standard when Brush brought out his first arc lamps. Ten-ampere series circuits are also the standard current rating for long-burning flame carbon arc lamps, which have recently been developed and are being extensively used in this country. Approximately 20,000 of these lamps have recently been placed in operation in Chicago. The voltage on a circuit varies, of course, with the number of lamps, reaching a maximum of 10,000 to 12,000 volts in some cases. There are, at present in use, two methods of securing the constant current required by series street lighting systems:

1. The use of a constant-current generator, in which the voltage varies with the load on the circuit.

2. The use of a constant-current transformer, which receives constant-potential alternating-current energy and delivers constant-current alternating-current energy, the potential of which depends upon the load of the circuit.

The constant-current generator may be either direct-current or alternating-current, but practically all arc machines are of direct-current type. It is noticeable, also, that practically the only type of direct-current arc machine that has survived is the so-called "Brush arc machine," which is a direct descendant of the original machine designed by Charles F. Brush back in the days between 1875 and 1880.

The ease of securing constant alternating current by means of the constant-current transformer, together with the general adoption of constant-potential alternating-current systems for general power supply purposes, has made the use of a-c. constant-current arc service very general. The invention some ten years ago of the mercury arc rectifier has also enabled us to obtain constant direct current from the constant-current transformers, using, as a source of supply, the standard constant-potential alternating-current systems that have now become standard. Therefore, the use of such constant-current transformers in conjunction with rectifiers has largely taken the place of the constant-current direct-current arc machines,

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and, as time goes on, the displacement of the arc machine by the rectifier will probably become more and more complete.

The advantages of constant-current operation, as compared to constant-potential for the operation of street lights, are numerous. They are so sweeping as practically to eliminate the constant-potential service for this purpose. They may be enumerated as follows:

1. The lamps may be lighted and extinguished from the central station exactly on any predetermined schedule. This is the fundamental requirement that has made necessary the development of a special distributing system for this purpose.

2. Constant-current circuits, as developed at present, have a relatively small ampere capacity (from four to ten amperes) and are available at a relatively high voltage (8000 to 10,000). Consequently, the investment in copper for distribution purposes is reduced to a minimum.

3. The constant-current arc lamp system is inherently stable, whereas the constant-potential arc lamp must induce its stability by means of a series resistance of considerable value. The amount of this series resistance is comparatively large in constant-potential circuits, since it is necessary to operate the arc on available commercial voltages which are higher than required. Naturally, therefore, this excessive resistance decreases the efficiency of the constant-potential arc lamp.

4. When metallic filament lamps are used instead of arc lamps on constant current, we also have important advantages. The filaments of the constant-current lamps are of larger diameter and shorter than those demanded by constant-potential lamps, and, as a consequence, the lamp is not only stronger and less liable to damage but also it is subject to smaller radiation losses on account of the smaller area exposed. This latter advantage is particularly noticeable in the "nitrogen-filled" lamp which holds out so great promise of future developments.

A system of street lighting which is a compromise between the constant-potential system for individual lamps and the constant-current system is one in which a series of lamps is operated across a constant-potential circuit. In this system 2200 or other available voltage is used to operate a series of metallic filament lamps, each series having a sufficient number of lamps to make the total voltage across the series the same as that of the line.

In order to prevent the breakage of a single lamp inter-

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rupting service on the entire series, each lamp is shunted by a special reactance coil. This coil is so designed that it takes but a small proportion of the total current of the system while the lamp is burning. If, however, the lamp filament should break, the entire current of the circuit passes through the reactance coil without danger to the coil. This characteristic is obtained by designing the iron circuit of the reactance coil so that it is operated above the bend of the saturation curve when passing the entire current of the circuit. At the same time, it is possible to obtain a curve of regulation, so that a considerable percentage of the total number of lamps on the circuit may be out of service before the current on the whole circuit is reduced beyond allowable limits. In this system we may see a return to a system which was used at least twenty years ago. The writer well recalls the use of these identical devices in the apparatus that was built in 1892.

This system has the material advantage that it does not require switching service for each individual lamp, but that this service may be accomplished at one point for an entire series of 30 to 35 lamps. Also, it is quite possible to group the switches for a number of circuits at one point. By this means, therefore, the cost of switching may be reduced vastly below what would be necessary if each individual lamp required this service.

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# SCOPE OF ENGINEERING DATA SUB-COMMITTEE

## REPORT OF THE SUB-COMMITTEE ON ENGINEERING DATA

PERCY H. THOMAS, CHAIRMAN

THE Engineering Data Sub-committee was created by the present administration and has therefore no established precedents to indicate the proper scope of its activities. The appointment of the committee grew out of the work of the original High-Tension Transmission Committee of ten years ago, under the leadership of its chairman, Mr. Mershon, in collecting engineering data about high-tension transmission plants and the similar work of the High-Tension Transmission Committee last year undertaken at the suggestion of Mr. Mershon, then President. The general approval of this collection of high-tension transmission data suggested the thought that valuable data might be collected in other fields.

The carrying forward of and the arranging for general use of the collection of data on the line initiated by the High-Tension Transmission Committee last year have been assigned to the present Engineering Data Sub-committee.

The broader possibilities of its work have been considered at some length by the committee, and while various practical considerations seem to introduce many limitations to the scope of its activities, there appears to be a legitimate and fruitful field for its work. It is the purpose of the present discussion to state briefly some of the considerations that are in the minds of the committee, and to ask that members will give the Institute the benefit of their criticisms and suggestions for the guidance of its future action. The committee would greatly appreciate the views of the membership concerning the scope of the committee's work.

From the point of view of the present discussion the engineering data desired by our members may be classed under several heads.

(a) Information of an exact character, which can be mathematically demonstrated or which universal consensus of opinion has definitely determined.



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Such data are theoretical formulas, physical constants, systems of measurements and units, in some cases accepted engineering standards, strength of materials and their salient qualities, methods of tests (in some cases), etc.

(b) Information as to forms of construction or elements of design which have been used by various individuals in solving such problems as are frequently recurring and the conditions of which are well understood by engineers in general. Such information will usually be useful to an engineer who has a similar problem to solve. In this class is such information as water turbine performance, steam condensers, transmission line construction, overhead trolley design, data on measuring instruments, etc.

(c) Information of a more specific character than that of cases (a) and (b), which applies only in special situations where the conditions of the problem are not easily described or understood by engineers in general. Such information would be of little use in connection with a different problem. Such cases would be the design of a special mining plant, many switchboard design layouts, building plans, etc. In this class fall most cost data. In such cases the uncertainty of the exact determining conditions of the particular reported case on the part of a distant engineer and the fact that these particular design conditions will rarely be repeated makes such information of relatively little general value. From this analysis it will be seen that only information of class (a) or class (b) would be of sufficient general utility to interest the Engineering Data Sub-committee of the Institute.

But in addition to the fact that there are many potentially available data that would not be valuable if collected, there are a number of other distinct limitations as to what material is practicable or desirable for an Institute committee to collect. Among such limitations are the following:

1. No data should be collected that are already available in satisfactory and convenient form.

2. No data should be given out with the approval of the Institute, about which there is not a general agreement among the best-informed engineers.

3. No data should be given out for advertising any commercial apparatus or individual.

4. It will usually be impracticable to collect data when the information is intimately connected with the private affairs

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of a company or where it would reflect adversely on the ability or judgment of the engineer in charge.

5. All information must be presented in such a manner as to make a clear distinction between the *opinions* of members of the committee or other engineers and actual fact data.

To summarize, it appears that information can be most successfully collected by the Engineering Data Sub-committee where the data sought are such as to apply in a large number of cases which are alike in their general underlying conditions and hence are of general utility; where the data are of such nature as to be readily given by engineers having the information and are at the same time capable of definite presentation to the Institute. Each subject proposed for consideration must be taken on its own merits.

The high-tension transmission data which the committee is now collecting are good examples of data of the desirable type. This line of information seems practicable to collect, definite and generally useful. When the committee has completed the collection of available data this information will be analyzed and correlated for publication.

Other possible subjects for the similar collection of data are: the use of current-limiting reactance coils; the use of synchronous power factor regulating apparatus; methods of locating grounds in cables; clearance lines on electric locomotives (but this is more properly the work of some of the railway associations), methods of erecting towers in transmission lines, high-tension insulation, electric drive in steel mills, etc.

The natural instigation on which the Engineering Data Sub-committee will initiate the collection of information on any particular subject will perhaps be through the suggestion of some person or persons seeing clearly the need for this information and confident of the practicability of securing it. Very often in such cases the collecting of the data desired may, however, not appear feasible to the committee.

When data bearing on some particular subject have been collected, as for example transmission line construction, the problem arises how to offer them to the membership. Such data may be in considerable volume and will contain many drawings. The expense involved in a complete reprinting of the data would be considerable, but a still greater objection exists in the fact that the data undigested and unanalyzed would be very difficult to use. The views of the membership are re-

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quested on this matter, both as regards data in general and more particularly as regards the high-tension data now in hand. The following questions are pertinent:

Shall the Institute assume the whole cost of publication?

Shall the data be sent to all the membership, in the PROCEEDINGS, and in the TRANSACTIONS as well?

Shall drawings of towers, insulators, switching arrangements, etc., be reproduced?

Shall the names of the companies be attached to their individual replies?

Shall the data be published in book form as was done in the case of the high-tension data collected ten years ago?

What position shall the Institute take as regards any assumption of approval of the data collected?

It is clear from the many questions arising when specific and concrete plans are considered for the collection and presentation of engineering data, that the scope of the work of the present committee must be an evolution continuing through years. We must work out each case as it comes along and the final result will shape itself.

The problem of collecting and presenting *exact* data, formulas and physical constants as outlined under (a) above, is another matter and comes more naturally under the handbook committee, of which Mr. Pender is chairman, and will not be here discussed.

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DISCUSSION ON "NOTES ON OIL CIRCUIT BREAKERS FOR LARGE POWERS AND HIGH POTENTIALS" (RANDALL), VANCOUVER, B.C., SEPTEMBER 11, 1913. (SEE PROCEEDINGS FOR OCTOBER, 1913.)

*(Subject to final revision for the Transactions.)*

**L. G. Robinson:** It seems to me that the subject of circuit breakers has been handled in a very masterful manner. The principles underlying the operation of the circuit breaker I agree with perfectly. The use of circuit-breaking devices dated back to the time when we used direct current almost entirely; it was found after the introduction of alternating-current circuits, that as the voltage of a circuit gradually increased, due to the necessity of longer distance in transmission and heavier loads to be carried on the circuits, that the more abrupt the opening of the circuit the better. Dr. Steinmetz some years ago published in the Institute PROCEEDINGS a very exhaustive treatise upon the effect of opening circuits abruptly, especially alternating-current circuits, and he used mathematical demonstrations and deductions to show what the effect would be in regard to oscillations caused by this sudden rupture of the current. The keynote of his deductions or summary was that you cannot open a circuit too abruptly for the reason that as soon as the current goes to the zero point in the wave form it is unable to re-establish itself and dies out naturally in the vibration.

However, as we get into voltages of more recent times ranging from 60,000 to 100,000 volts and more, there is introduced the great difficulty of acquiring switches and circuit breakers which will operate in a sufficiently short time as cited in this paper. The ponderous nature of switches for such voltages make it almost impossible to move them with sufficient rapidity to interpose that gap in the required time. And if it were possible to move them we would then be face to face with another condition of stopping them gradually and not causing any breakage or damage.

Some seven or eight years ago in the design of the preliminary plans for another transmission system than the ones mentioned I felt that it was necessary to devise some kind of a mechanism which would accomplish the result of interposing this gap without having to use such a ponderous piece of mechanism, and it occurred to me that the use of several gaps in series, opening simultaneously, would accomplish this purpose. I am sorry now I have no experiments to point to, nor measurements from which we can gain further knowledge of the subject, but it seems to me that, from purely an academic point of view, we might be able to draw some deductions from the consideration of the features just now suggested.

We are all familiar with the distribution of the voltage in an arc—the general curve of distribution of voltage in an arc. At each terminal there is a rapid drop of voltage, and the intervening space between the short distance from each terminal to the

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other terminal would be a gradual drop, it is less steep then near the terminals. Now, good sense would denote that if we interpose two gaps where we formerly had one we would take advantage of the steep drops at the terminals at twice the number of points which we would in the first instance. Going several steps further and introducing as many gaps as may be found necessary by experiment, we might introduce 16 or 20 gaps for extremely high voltages and secure thereby a very steep curve of distribution of voltages across the opening. The total summation of the openings between these several openings and series need not be as great as one single opening of a single contact, for the reason just cited, namely, the distribution of the voltage across the opening.

The maximum movement which would be provided for the operation of such a series of openings, could very well be small, and the switch would operate with a very short throw so that the momentum gained by the moving parts need not be as great as when you have one or two breaks with longer motion.

I do not think that I have discussed this matter with more than one or two men in the electrical engineering business, but every person with whom I have discussed it has signified his desire to see some such matter tried, and I would be very grateful indeed, if any one of us was in a position to attempt such experiments, if they would do so for the benefit of the engineering fraternity.

**John B. Fisken:** There is one point which strikes me in connection with this proposition of using reactance in connection with the breakers. Before I come to that I might ask whether the opening of the main contacts necessitates the opening of the reactance contacts, also, is it possible under this arrangement for the main contacts to open in a momentary effort which would clear itself and leave the reactance contacts closed? The other point I wish to raise is this: The oscillograph record of Fig. 4 is taken from opening a breaker on 12,000 volts, and 16,000 amperes, and shows practically no resonance. Now, what is going to be the effect if we introduce the reactance as proposed on a switch having 200 or 300 miles of line at 60,000 to 100,000 volts, where this reactance is in series with the capacity of the line? I think that the oscillograph record would be very different from that shown in Fig. 4.

**W. H. Fraser:** This method I believe was first tried by the Canadian Westinghouse Company with the type of switch used at Niagara Falls. In this case the arrangement was only temporary, and in place of a reactance, a resistance was used when the switch opened.

Certain points might have been more definitely brought up in the paper as to the circuits on which this type of switch ought to be used and the amount of reactance which should be introduced.

Another point which ought to have been referred to on this

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subject is,—What is the breaking capacity of an oil switch? This depends upon so many variable quantities, such as the time setting of the relays, the type of circuit, and the capacity of the generating equipment, that some definite remarks might have been made in the paper in order to cover conditions which vary according to each individual system. It would appear that if the main and the auxiliary contacts in this switch were both operated by one mechanism, sufficient time lag would not be introduced between the operation of the two contacts in order to allow the reactance to come into play; but Mr. Miller may be able to give more definite information in regard to this.

At present, we have two companies developing oil switches along two entirely different lines; one company developing a switch which introduces a reactance, while the other has developed a switch where the auxiliary contact is broken inside an explosion chamber placed in the main body of the oil.

With reference to Mr. Robinson's remarks, the type of switch suggested by him might be conveniently arranged for outdoor work but would be totally unsuitable for indoor work unless considerable expenditure was incurred to provide buildings of sufficient size.

**C. F. Terrell:** In reading Mr. Randall's paper I was very much interested in this type of circuit breaker discussed therein. This reactance breaker appears to be a solution of the problem of taking care of short circuit conditions on systems with heavy transmission lines and large generating capacity. I ask Mr. Miller if this type of breaker is in use in very many plants at the present time, and what results have been obtained during the time that they have been in service?

**Vladimir Karapetoff:** This paper must be taken as merey a description of something that has not been thoroughly tried in practise, and we ought to be cautious and not to be too quick in adopting these switches. I do not wish to pour cold water on any innovation offered, and no one more than myself appreciates the splendid work done by our different manufacturing companies in developing new types of apparatus, but we all know how large operating companies had to suffer and are suffering now from the results of quick adoption of something new. We have had many "patent medicines" offered us, and with a patent medicine, the effect is usually exhilarating at first and the reaction comes in much later. However, those who are in a position to try these breakers in proper quantities might do so. I am told on good authority that such breakers are prescribed for the new Los Angeles aqueduct, so that you people on the Pacific coast will probably hear about their action. Unfortunately it may be two or three years before a real conclusion can be reached as to their effect. It is also possible that the reactance contacts will be disconnected at any time and the switch operated just as an ordinary switch.

My first question, of course, was like that of one of the preceding

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speakers—is it possible to open the main contacts and not open the reactance contacts? But very little reflection will show that this is the only possible way, because the reactance is very small—I mean the size of the wire—and it is incorporated with the switch to carry a load for a small fraction of a second, so that it is impossible to carry the line current over it; once the main contacts are open the reactance contacts will be also open a moment later. Some years ago the large operating companies and distributing companies, mostly in the east, were driven to the necessity of using reactance coils in series with their generators—the necessity for protecting the generators against heavy short circuits; of course it is not an ideal solution to have a ballast on your line all the time and I use the word "ballast" advisedly, because reactance acts as inertia, so it consists of ballast. Probably I am not the only one who thought that such a reactance ought to be introduced into the circuit only in the time of need, but when I spoke to operating engineers they very clearly explained to me that it is impossible, that the time is too short, that when the reactance is needed it must be there; further it must be in the circuit all the time. But somehow I could never reconcile myself that this was a necessity, and I am exceedingly pleased to see how this particular company handled the subject and said "no, it is possible to introduce reactance at the moment of the need, and not have the ballast there all the time".

Now, some criticism has been made in regard to the oscillograms appended to this paper. For instance, Fig. 2 probably is entirely self-evident to the writer of the paper and to those who are familiar with this particular branch of the work, but I must confess I do not understand it; neither do I understand very clearly the meaning of Fig. 4, and I should like very much if Mr. Miller would be kind enough to explain it to us as if we were absolutely ignorant as to what it means. The zero line here is at the center, and there is current marked number 1 and number 2; all these things are not self-evident, and I think we ought to put aside our pride and just ask what all this means.

**A. A. Miller:** I wish to make an explanation of the conditions under which this paper was submitted to me for reading. I do not profess to be sufficiently expert in the design, operation or analysis of circuit breakers to pose as being able to answer all these questions. Mr. Randall nominated me to read his paper, and he gave me no explanation of the oscillograms regarding which Prof. Karapetoff has asked for explanations, so I am somewhat at a loss to answer some of the questions.

With respect to Mr. Fisken's question as to the reactance contacts necessary to opening the main breaker contacts. I think Prof. Karapetoff has answered that; the contacts would open together mechanically; the main contact starts to open, the reactance contact necessarily must follow. As to the matter of voltage rise due to the introduction of reactance, Mr. Randall states in his paper he does not know of any tests that have been

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made in which oscillograph records have been taken under actual conditions; there is a voltage rise at the moment of disruption of the circuit. I have an oscillogram here in connection with some technical data. The test was made in connection with an 88,000-volt, 60-cycle three-phase circuit breaker of the reactance type; the voltage surge at the moment of completely opening the circuit shows some rise but not as much as one would expect. I do not believe, however, this test was made with any such capacity as represented by a long transmission line, so in that sense it does not answer your exact question.

With respect to Mr. Fraser's question as to the limit of reactance—that is, how much reactance would be inserted in each circuit, depending upon the reactance of the apparatus connected to the line—I am not able to state.

The time lag existing between the opening of the main contacts and the secondary contacts or the reactance contacts is pretty well shown in Fig. 4. The curves as shown here (Fig. 4) were obtained in tests run primarily to determine circuit breaker characteristics. They are typical curves taken on one phase of a 25-cycle, three-phase, 12,000-volt circuit, the reactance breaker being equipped with an instantaneous trip. The short circuit occurs at *A*; at *B* the main contacts opened, cutting in the reactance. This reduced the current, as is shown by the markedly reduced amplitude of the current wave; and at *C* the reactance contacts opened clearing the circuit. It is seen there is no noticeable voltage surge in the voltage curve at the point corresponding to time *C*. The opening of main contacts on this breaker occurred in about 2½ cycles (about 0.10 second) and the circuit was cleared in about 5 cycles (0.20 second).

The voltage curve 2 (Fig. 4) is across the contacts of one main pole of the breaker, hence the voltage does not appear (at the left of the oscillogram) previous to the appearance of the current in curve 1.

It will be noted that the reactance reduces the current from about 16,000 amperes to 3000 amperes or something over a 5 to 1 reduction. The final break is made with a smaller current, thus reducing the possibility of a voltage rise.

When meeting these conditions of limited voltage rise, the reactance breaker can clear the circuit in a shorter time than the single step form of breaker. The work is done in two steps—and although the first step produces the greatest reduction of current, it really makes a very small disturbance inasmuch as the rate of change is comparatively low. The second step will therefore have but a small proportion of the initial current to break, which is a small proportion of what the single step form of breaker would have. The single step breaker makes an infinite rate of change in cutting the maximum flow instantly to nothing, and therefore produces the maximum of potential surge. When the first step of a two-step breaker acts, it still leaves a closed circuit in which the stored energy of the apparatus and

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system will dissipate at a relatively slow rate; whereas in the single step breaker this energy has to be absorbed instantly or is dissipated in destructive arcing under oil.

The reactance coil units for circuit breakers up to 22,000 volts consist of one well-insulated coil for each pole mounted in the expansion chamber of each pole on substantial treated wood strain insulators. For breakers from 25,000 to 110,000 volts the construction of the reactance coils is similar to that of high-tension core type transformer coils. These coils are substantially mounted and are completely submerged in oil.

The ultimate breaking capacity rating of a circuit breaker is expressed in terms of the total normal rated capacity of generating and synchronizes apparatus on the circuit on which the breaker is used, and this rating therefore varies with the conditions that may limit the short-circuit current. In defining this breaking capacity the breakers are considered to be connected direct and close to the source of power and the rating is based on automatic instantaneous overload tripping in connection with generators having approximately 8 per cent inherent reactance and having the maximum rated voltage applied. Any departure from these conditions will change the relative rating. When the breaker is used non-automatic or with a definite time element of two seconds or more, the ultimate breaking capacity will be doubled. This is because alternating-current generating apparatus will develop on the first few cycles immediately following direct short circuit, from five to fifty times full load current, limited only by the inherent reactance of the apparatus itself. The tendency of the short circuit current is to decrease after the first few cycles until at the end of one or two seconds it reaches but two or three times full load current. This value is known as the "sustained short-circuit current" of the apparatus. The rate of decrease varies with the different forms of machine, even with those having the same maximum and sustained short circuit current. As can be seen from this, the amount of current interrupted by a breaker tripping on short circuit, depends upon the time elapsed after the short circuit at which the breaker is tripped. Therefore the instantaneous relay trip breaker operates under more favorable conditions of current interruption than the instantaneous direct trip breaker. The relay trip breaker opens the circuit at a later time than the direct trip, and the current interrupted is therefore less. All reactance added between generator and breaker will increase the breaking capacity in direct proportion. If the generator has an 8 per cent inherent reactance and the lines and intervening transformers have also 8 per cent reactance, the breaking capacity will be doubled.

As to Mr. Terrell's question as to what installations of reactance type of breakers have been made, I am unable to answer, other than that certain breakers have been built and installed; where and how many I don't know. I know the type has been

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developed within the last eighteen months or two years. That last remark also is a sort of reply to Prof. Karapetoff's statement that he considers it rather dangerous to launch forth too rapidly —for operating companies to launch forth too rapidly—in the adoption of comparatively untried apparatus. Of course the manufacturing company is placed in the position of having to depend on the use of its product by operating companies, and it is in connection with the results obtained under actual operating conditions that we learn; so someone has to be the "victim," but we try to limit that as far as possible.

With respect to the use of power limiting reactance, I think the original condition which brought about the apparent necessity for apparatus of this sort was the tremendous short circuit currents which developed where very large generators are used. The immediate effect of such a short circuit is apparent in the destruction of end windings of the generators. It was an easier matter to introduce power limiting reactances than to rewind a great number of machines, which involved in itself a large expenditure of money.

With respect to the oscillograms of Fig. 2 I have made a study of them and possibly can throw some light on them. The two halves of the oscillogram must of course be considered together.

Observe that the upper and lower oscillograms of Fig. 2 are to be considered together as showing what happened at the time of making this test. The connections used were very simple and consisted of a three-phase line, 12,000 volts, 25 cycles, leading to the breaker illustrated in Fig. 1. On the load side of this breaker a short circuit was established and the oscillograph so connected as to record the current flowing in lines 1, 2 and 3. The upper half of Fig. 2 shows current in lines 1 and 2 and the voltage between lines 2 and 3. The lower half of Fig. 2 shows the current in line 3, and the voltage between lines 1 and 2 and 1 and 3 lines. The voltage connections were made on the line side of the breaker, such that after the rupture of the arc the line voltage record continues to the end of the oscillograms. The arc voltage established between contacts would thus be the voltage across two arcs in series for any phase considered. By careful observation the half cycle existing between the end of the zero line of number 2 voltage, at the middle part of the oscillogram, and the end of number 1 current, can be seen in the upper oscillogram, but the half cycle is not thus apparent in the lower oscillogram, although I am advised by Mr. Randall that this was plainly shown in the original oscillogram.

It may be added here that it is preferable that the current die out along its normal wave shape, as in this way the minimum of energy will occur, while with an abrupt interruption, the resultant potential may be very high.

**V. Karapetoff:** I wish to mention something that I read just a few weeks ago, a short note on some work done abroad. They superimposed a high-frequency current upon the current to

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be opened so as to obtain many more zero points than is possibel on the normal frequency. Just imagine an ordinary sine wave, and superimpose upon it a sine wave of much higher frequency, now add the two curves; you can easily see that the resulting curve will have many more zero points than the original low-frequency curve; in other words you have to wait, say 1/120 of a second, at 60 cycles, until you get to zero; but when you superimpose the high-frequency current upon the line current then the instant will come much sooner at which the superimposed current is equal and opposite to the line current; so that you offer the arc many more chances to be extinguished within a shorter interval of time. I do not know how this high-frequency current is produced and how far it is possible to apply it for commercial purposes, but I think the idea is quite original and logical.

I wish also to state, in regard to the advisability of using this new proposed type of circuit breaker, when a low-frequency traveling wave or surge comes to a substation, Prof. Steinmetz's investigations show that it is these traveling low-frequency surges that are most destructive to the apparatus, for the reason that they carry the largest amount of energy in them. Now, then, I should like to know if it is not harmful to open the circuit too quickly when you have a traveling wave coming into it? Because that large amount of energy—which is not a fluctuating energy, but a fairly constant amount of energy—when it comes something has to dissipate it, or else, as my mechanician says, "something will have to go".

**Ford W. Harris** (by letter): It is known that the older designs of oil circuit breaker are violently explosive at times. Quantities of gas form in the tanks, which are ruptured or blown entirely off. This extreme condition is not always met on heavy short circuits and is of variable magnitude. The gas cannot be entirely explained in some cases except upon the supposition that the contacts failed to separate entirely or at least separated slowly. One reason for this is to be found in the fundamental design of most of the old style breakers as shown in Fig. 1. In this design we have a tank 1 which is tightly secured to a support 2 through which an operating rod 3, generally of wood, passes, this rod having an area of from one to two square inches. The rod 3 has a sliding packing washer 4 to make a tight joint where it passes through the support 2. The tank and the support form an only partially vented chamber. The rod 3 is moved downwardly to separate the movable contacts 5 and the stationary contacts 6. Immediately thereafter a gas explosion takes place in the tank, producing a pressure which in extreme cases may reach fifty pounds to the square inch and exert an upward force of from fifty to one hundred pounds upon the rod 3. This is because the rod is to all intents and purposes a plunger and behaves exactly like the plunger of a pump. Generally there are three poles to an oil circuit breaker and a total upward pressure of as much as three hundred pounds

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may follow such an explosion, this pressure tending to close the breaker, reestablish the arc and make more gas.

As such breakers usually open by gravity with an impelling force of not over fifty pounds it is not hard to see why they are blown partially closed and why the arc holds on and the breaker is destroyed.

The resistance breakers shown in Fig. 3 of Mr. Randall's paper were the first thing of this kind ever attempted on a large scale. Seven of these breakers were installed in the Long Island Station of the Pennsylvania Railroad. I am glad to note that Mr. Randall calls this a successful form for it was my impression that these breakers were only very moderately so. They were designed to go in the space taken by old style breakers of conventional design and to be interchangeable with them as far as bus construction, compartments, etc., were concerned. The problem of putting a resistance insulated for 11,000 volts in the same space as that required for a pair of contacts was a hard one. The amount of resistance material was limited and the insulation very difficult. These breakers were tested repeatedly on dead short circuit and stood up perfectly on such tests, where conventional breakers had repeatedly failed. They do not represent, however, a fair test of the resistance principle, although the fact that they held up at all is rather a vindication of that principle.

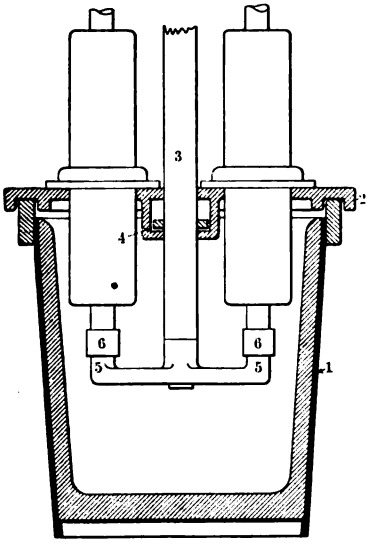


FIG. 1

There is no question that reactance breakers are an improvement over the forms which were standard five years ago, but a great deal has been said and written about their virtues which will not stand the test of critical examination. For example, take Fig. 4 of Mr. Randall's paper and the note immediately beneath it. I do not suppose that Mr. Randall means us to infer that there is some particular virtue in the reactance that has reduced the current from 16,000 amperes to 3000 amperes. As a matter of fact the first wave of current measures 16,000 amperes but this is very much unbalanced and really represents a balanced current of about 11,000 amperes. This current has died down to approximately 8000 amperes unbalanced or about 6000 amperes balanced in the wave just preceding the zero B. Now from A to B the breaker has been wholly closed, as shown by curve II, which shows the zero voltage across the terminals of

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the breaker. This reduction from 16,000 amperes to 8000 amperes unbalanced or from 11,000 to 6000 amperes balanced is no more than the natural dying down of the circuit due to generator characteristics and would occur on any breaker that remained closed for one-fifth second after the short circuit occurred, as most of them would. There is therefore no special virtue in the resistance breaker during this period. The reactance was inserted by the opening of the main contacts on the wave just before the point B is reached. The current was reduced from about 6000 amperes balanced to 3000 amperes balanced at this point. The reactance was in circuit from *B* to *C* with a very slight decrease in current, and the circuit was opened at *C* by reducing the current from 3000 amperes to zero. In other words the current fell, due to generator characteristics, from 11,000 amperes to 6000 amperes, the main contacts reduced the current 3000 amperes and the auxiliary contacts cut off the remaining 3000. The advantage of the reactance breaker then lies in taking two bites at the circuit and not in any marvellous reduction due to the reactance.

Now in my opinion, leaving aside constructional details, a resistance is theoretically superior to a reactance for this purpose on account of the conditions on the final break. It is not generally appreciated that an arc of several thousand amperes and from one to twelve in. (2.54 to 30.4 cm.) in length may be maintained in oil with a drop of a few hundred volts provided there is sufficient steadying ballast in the circuit. If it were possible to experiment with a direct current of five thousand amperes at ten thousand volts it is almost certain that four arcs each six inches long could be maintained in oil indefinitely, the drop across the four being about one thousand volts, the other nine thousand volts drop taking place across the generators, wiring etc. Such direct-current arcs would be quite stable, and alternating arcs are nearly as stable except that they do not readily re-establish themselves. Of two alternating arcs fed from the same source and each carrying the same current and having the same drop in voltage, the one in which the ballast is largely inductive will be the most stable This is a matter of common knowledge to arc lamp engineers and applies exactly to the oil circuit breaker problem. For that reason I believe that theoretically the resistance breaker is superior to the reactance breaker, although both are a step in advance.

Mr. Randall is undoubtedly correct in stating that reactance breakers may be designed that will take care of any condition that can be met, but it is also true that resistance breakers can also be designed which will be fully or perhaps more efficient

I am not, however, sure that it is necessary or desirable to go to either. The conventional designs are much simpler and it is my opinion that a multiplicity of ordinary breaks in a properly designed chamber will be found adequate to open any existing circuit. Such breakers would be manifestly cheaper to build.

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DISCUSSION ON "A MODERN SUBSTATION IN THE COEUR D'ALENE MINING DISTRICT" (FISKEN), VANCOUVER, B. C., SEPTEMBER 11, 1913. (SEE PROCEEDINGS FOR SEPTEMBER, 1913.)

*(Subject to final revision for the Transactions.)*

**W. V. Hunt:** I have listened with great interest to the paper read by Mr. Fisken, and I was particularly interested in the design of a substation that could, if necessary, become a portable substation, inasmuch as it could be moved to another district.

I think in some cases we might go further with the design of substations with that idea in view; we have some substations that are more portable than that, as they are built on standard railroad cars, and we can take them around on our system, and I think this idea might be extended to some mining districts, keeping the capacity of the substation within reasonable limits. We may adopt a substation on the lines of the one developed by Mr. Fisken in some districts adjacent to Vancouver.

**Frederick D. Nims:** I have talked this subject over with Mr. Fisken considerably during the last year or two, and I think his station and one that we might build would be very much along the same lines; I think there are a few points that we cannot agree upon, one being that he leans a little bit too much to three phase transformers. In putting in a station such as he describes, with three 650-kw. three-phase transformers, personally I would prefer to put in transformers of a slightly higher voltage, connecting them in delta, having an opportunity of running open delta with one transformer disconnected, if the occasion should arise. This, is merely a difference of opinion.

I ask Mr. Fisken to what capacity he thinks it is possible to carry the automatic idea. Personally, I do not see any reason why it should not go as far as you like. Also, from the illustrations, it would appear that a single circuit of 60,000 volts goes into the substation. From what distance does that single circuit run over a double circuit line, or to what extent is the station dependable on a single circuit, in miles?

I have seen the water relay and it is very ingenious indeed, but the comment which I made to Mr. Fisken is, I think he has gone a little bit too much to automatic devices and not left quite enough to the man who goes around to look after the station.

**W. Fraser:** I believe that the use of portable substations or semiportable substations will become more usual in the future than it has been in the past. The cost of operation is actually reduced and I think that is what all companies are trying to accomplish at the present time.

Mr. Fisken did not give us the type of the lightning arrester, nor state whether they are charged bi-weekly or daily; I expect it is daily charging, however, because it seems that a patrolman is on the scene, and therefore it might be convenient to charge them daily.

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I think the features of the daily over the bi-weekly charging warrant the installation of the daily charging arrester.

**C. F. Terrell:** I rather question the use of water-cooled transformers for this class of service; the use of self-cooled transformers means a higher first cost, but on the other hand gives greater simplicity and reliability, freedom from troubles that attend equipment for supplying cooling water, and it would probably be possible to have the substation inspected by the patrolman at less frequent intervals.

**L. G. Robinson:** The improvement of the automatic substation is undoubtedly going to be a great boon to the railway men who have the electrification of trunk lines at heart.

A great deal of fault was found with the high cost of electrification of trunk lines, and a good deal of that high cost is due to the permanent nature of the substations which have to be built for the purpose. Many features were responsible for this high cost of permanent stations, and principally among them were the idea of continuous service and substantial construction for the high factor of safety recommended by Prof. Karapetoff—a high factor of safety of course is always accompanied by heavy and expansive construction—and I think we can all admit that a high factor of safety in regard to automatic substations can be attained with the acquirement of these automatic features. The station does not have to be built upon heavy lines, of solid concrete; the B. C. Electric Railway Company have succeeded in building a substation which can be carried about on wheels, and Mr. Fisken has succeeded in building a substation which can be moved about at a minimum of expense. Together with this comes the idea of automatically cutting out faulty lines in order that operation may go on uninterrupted. That, I believe, up to the present time has been considered an impossible feat. I know that companies with which I have been connected years before this have operated under great difficulties from this particular feature—they have not been able automatically to cut out high-voltage transmission lines.

I agree with Mr. Nims that a good deal of responsibility should be placed upon the operator, and we must depend upon his " personal equation " so to speak; when the operator finds difficulties there usually is a time element sufficient for him to make up his mind whether he will hang on or cut loose, and that, as a rule, in the past has been the safest procedure—his balancing the cost of interruption against the cost of damage from hanging on.

**J. A. Lighthipe:** Are you attempting to use telephone transformers between your high-tension line and your telephone? We have in Los Angeles two portable substations of 750 kv-a. capacity, on a heavy 15-ton truck, and we pull this truck all over the country roads, sometimes in the case of emergency with an automobile truck; it has been of the utmost service to us

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in helping out some of our substations with burned out transformers. It is also very valuable for conventions and illuminations and things of that sort, where there is for a short time, a week perhaps, a very heavy illuminating load on a certain portion of the town where it is not provided for, except with high potential loads.

**A. A. Miller:** This matter of automatic substations is attracting an increasing amount of attention. Some of you have undoubtedly read the paper, which was presented by Mr. Summerhayes at a comparatively recent meeting of the Institute, which paper appears in the June, 1913, PROCEEDINGS, describing an automatic synchronous converter substation used in the city of Detroit. That station has in it apparatus which is occasionally looked upon as being somewhat difficult to operate, but notwithstanding these difficulties, the automatic starting, synchronizing and adjusting are said to be successfully accomplished, and the synchronous converter made to carry its proper share of the load; all of this being done by means of the single alternating-current circuit provided for supplying power to the substation.

It is reasonable to predict that a somewhat extensive effort will be made to perfect automatic apparatus, and to weed out any defects that may exist, which are only to be discovered by continued use and diversified application, and after the reliability of the equipment and the practicability of the idea are thoroughly established, we can rationally expect considerable use of automatic substations.

There may come a time when such substations will be used in railway trunk line electrification, but the reliability of the assembled parts, working as a whole, must be pretty thoroughly demonstrated before we can expect such application.

Portable railway substations have been successfully used for some years. They involve, in nearly all instances, alternating-current transformers, for reducing to the proper voltage for the rotating equipment required for direct current, generally of 600 volts potential. Sometimes synchronous converters are used in such portable substations, and sometimes motor generator sets, depending upon the individual preferences of the engineer selecting the equipment and the exigencies of the particular application. I believe that portable alternating-current power substations, both single-phase and polyphase, can be used to great advantage by many power companies. The field for such outfits is surely enlarging rapidly, and the moderate voltage transmission lines, or more properly termed, intermediate voltage distributing lines, are now penetrating many farming and agricultural districts, a class of business not particularly sought heretofore. The result is an increasing number of relatively small substations, the total weight of the apparatus involved being no unwieldy amount. Many of these substations are of the outdoor type, and the form of

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construction used makes it possible to provide for easy disconnection of the permanent apparatus, and the quick substitution of a portable equipment. It seems to me this idea is entirely practicable, and that the portable alternating-current substation is bound to become a very handy tool for the power companies.

**R. W. Pope:** In speaking of the developing of automatic stations and machinery, it occurs to me that a recent law of the state of Washington requiring an additional man at substations might stimulate the invention of automatic devices so that instead of one man there would be no man in attendance.

In visiting a station of this kind attended by one man I happened to glance at the instructions for resuscitation and the name of the nearest doctor to be called, and it occurred to me that, possibly, was one of the reasons why the law was being agitated requiring a second man to be in attendance—in case of the disability of the other one.

The development of the automatic telephone system, I think, is one that might be well studied. Of course the conditions are entirely different. Another instance is the automatic block signals of the railroad companies. The manual system has to a large extent been displaced by the automatic, it having been found that the latter is particularly reliable compared with the attendance of an operator.

**R. F. Hayward:** The question of the design and operation of transformer substations for large high-tension distribution systems is of very great importance on the Pacific Coast, where wages of operators are very high.

Where operators are employed in transformer stations, it is generally necessary to employ three shifts, and often, as a matter of personal safety, a second man on a shift is employed. If this sort of thing were done for anything but large and important transformer stations, it would run up the operating costs of the distributing system so much that no profitable business could be done in a scattered district.

The time was when current from 2000-volt lines was served to customers through the medium of transformer stations, but now outdoor transformers are in very general use on 12,000-volt distributing systems, which are operating with as much ease and economy as the older 2000-volt systems. Consumers are connected at any point on a 12,000-volt line, through the medium of 12,000-volt transformers placed on poles.

It is only a step from 12,000 or 20,000 volts to distribution at 60,000 volts in much the same manner.

The tendency at the present time is to treat the transformer as part of the line, and if 60,000-volt transformer installations are developed along the lines of Mr. Fiskin's design, I do not think it will be very long before a 60,000-volt distribution system can be tapped for service at any point where the demand may occur. The only difference between 60,000-volt and 12,000-

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volt installations will be that the units dealt in will be larger in the former than in the latter.

The demand for the supply of power to mines and smelters has been one of the principal causes of the rapid development in long distance transmission during the past fifteen years. The exacting requirements of the power supply for these purposes have taught operators their most important lessons in giving continuous service.

But of all the lessons learned in the West, the greatest seems to me to be that mechanical strength in line construction, and simplicity of arrangement of switches and connections, will go much further towards continuous service, than duplication of lines, switches and transformers with complicated connections.

Simplicity of connections—whether it be in the generating station, transmission line, or transformer station and distributing lines—is, I believe, the keynote to success in giving continuous service.

**V. Karapetoff:** This question of delta versus Y connection seems never to lose its interest and it is one of these questions that I do not believe will ever be settled because the conditions of operation are changing, and the apparatus, the safety, and the reliability desired are also changing with the progress of the art. Personally, I believe that this connection—delta—Y—probably with considerable impedance between the neutral and the ground is a condition that is applicable to a great many transmission systems, notwithstanding I have found systems that operated delta delta or Y Y, and I should like to hear some expression of opinion from those who have the most recent experience as to how the matter stands now.

Mr. Fisken mentions an automatic device for indicating when the fuse wire blows out. Some years ago I was connected with a large transmission company in the east and we had this trouble. Some branch lines on a 60,000-volt circuit were protected by copper fuse wires about 16 ft. (4.8 m.) long, placed in rubber tubes, and at night one of these wires would blow, and a little town or factory would be without light or power and the question was put to me to find some kind of indicator that would notify the nearest patrolman about this occurrence. So I went to the principal manufacturers of this kind of apparatus and suggested all kinds of devices that they could furnish, but one of the representatives finally told me," You do not need any complicated apparatus, all you need is to attach a weight to your wire so that when it blows the weight drops and closes a circuit that rings a bell in the patrolman's cabin." That was a simple idea, and it did me a great service.

**John B. Fisken:** Mr. Hunt suggested portable substations on flat cars. I wonder if Mr. Hunt has ever been in a mining district? If we could only get an aeroplane that would lift a 650-kilowatt transformer up to one of our substations it

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would be a great help. We have one or two substations where we have as much as 30 or 35 per cent grade to get material up. There is much to be said, however, in favor of the substations on flat cars or on wagons if the country is suitable.

Now, our distribution is not entirely mining. Out of 550 miles (167.6 km.) of 60,000-volt lines, I suppose more than half of it is in farming country with substations scattered all over it, and therefore there is no doubt that the flat car substation might be a very good adjunct to our business; the unfortunate part of it is that the " pickings " are awfully thin. In order to make anything at all we have got to keep down our investment, and when we make our rates we have it understood that we will do the best we can to give a constant service, but we cannot undertake to keep spare transformers in every station, or even go to the expense of maintaining a substation on a flat car. We do keep spare transformers at important points ready for shipment, and we can load a transformer and easily have it started on the road in about two to three hours.

Referring to Mr. Nim's discussion, I do not see any reason why we should go to the expense of hauling three transformers up a mountain side when we can haul one. The weight per kv-a. of three transformers is greater, the space required for them is greater, and when you have to excavate in a mountain side to get some place to set them so they won't roll to the bottom that is quite an item. There is one advantage that Mr. Nims points out, that is, in the event of a burn-out in one transformer, if your connections are delta delta you can cut out one and run open delta. The three single-phase transformers have six points of weakness; they have six entrance bushings, the three-phase transformer has three, which cuts down the liability of trouble to that extent; but the prime reason why we adopted the three-phase transformer was that our first 60,000-volt line was built into this mining country. Twelve years ago we did not know anything about it, we had nothing to guide us, and the factory engineers recommended three-phase transformers; we took their advice and after ten years of operating experience we have never seen any reason for changing our plans. Where we have three three-phase transformers, we might substitute three single-phase transformers, but we use these three-phase transformers in all our stations, and in many places we only have one transformer, which would mean, if we used single-phase transformers in these stations, that our other spare apparatus would not be available.

Mr. Nims asked the question as to what extent the automatic idea could be carried. My opinion is that there is no limit, it can be carried to almost any extent.

Another question was about the length of the single circuit. This station is 400 ft. (121.9 m.) distant from the main lines, which are in duplicate. The two lines, up to a certain point, follow different routes, on different rights-of-way; at a point

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about twelve miles from this particular substation they come together. At that point we have a 60,000-volt switching station, equipped with oil switches, electrically controlled. There we can, by putting the two lines on the same bus at one of our stations, switch the load from one line to the other in case of repairs, which we do frequently. In case of trouble of course we can either switch at this particular switching station or we can transfer the branch line by means of the air switches to either of the main lines. At a point some twelve miles beyond we have another 60,000-volt switching station of oil switches, so that we have considerable flexibility. The duplicate line has not been used to any extent except for repairs. The question of the length of a shut-down in the mines, provided it does not extend over a long period, is immaterial. A large part of the load is in the concentrators. If the power goes off, the concentrator is choked and it has to be cleaned out and started over again, so that the question of whether it is off for 15 minutes or two hours is not very material; the big loss to the mining company is in getting started again.

Mr. Nims suggested that there is too much left to the automatic features, and not enough to the attendant. I do not know whether this contention is right or not, but the attendant claims that he has too much to do; he has to take care of a line that rises to an elevation of about 3000 ft. (914 m.) above where his station is located—there is no road, but there is a rough trail, and he has to go up there five miles (8 km.) very frequently; he has another line about 8 miles in length to take care of, and a third line about the same length, so that the attendant is very seldom at the station. His house is only a few hundred feet away so that when he is at home he is available; but the station is designed to do without even this attendance; all that we require of him is, as I have said, to change the charts on the recording instruments and make a general inspection of the plant. I think, for that reason, all the automatic features I have outlined are necessary. I might state that in the early days what really started us on working out these automatic features was an occurrence that happened at this same plant, although at that time it was an old substation. I got a call one Sunday morning about six o'clock, telling me the transformer 275 kv-a. at Bunker Hill was burned out. I had just time to jump into some clothes, make a rush and catch the morning train. I reached there about one o'clock and was met by one of the men who said it was all right. He said " The water stopped running and the transformer got hot." I went down and looked it over, everything was all right; but that was the time when it occurred to me that it was necessary for us to have some means of protecting our transformers in case of a recurrence of a shortage of water, and the " auto trip " or " water relay " was the result. The first water relay we built was a very crude affair, which has gone through a number of stages before we finally adopted our present type.

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In answer to Mr. Fraser I would state that the lightning arresters are of the electrolytic type, and are charged daily. The patrolman usually gets back home at night; if he does not he telephones in to one of the mining company's men to charge the arresters; but as a rule he attends to them himself.

Mr. Terrell questioned the use of the water-cooled transformers, and his contention I think rather well founded. Unless there is a water supply under gravity, I do not favor the use of water-cooled transformers, and in our practise we are getting away from them. Our first transformers used in the Coeur d'Alene country were all water-cooled. Our experience now is that up there it is the hardest thing in the world to get water. The mining companies actually pump the water for the concentrators two or three times; after the water has gone through the mill they catch it and pump it up again, so that we have been compelled on that account to get away very largely from the water-cooled transformers; but whenever a supply of good water under pressure can be obtained the saving in the cost of handling a water-cooled transformer as against an air-cooled certainly justifies the use of the water-cooled transformer, especially where you have to haul them up the side of a mountain.

Mr. Robinson suggested automatic substations for railway electrification. If you gentlemen ever come to Spokane, and I hope some day you all will, you will have an opportunity of seeing automatic substations on an electric railroad. The Inland Railway system covers about 100 miles (161 km.) of single-phase railway where the substations are entirely automatic. I am not very familiar with the apparatus there, but I do know that I have never seen any attendant. As a general thing substations are located close to a depot, and the agents, when they are not telegraphing or making out waybills or doing something else go across and look at them; they have worked out the automatic substation for railway electrification.

In regard to our chairman's question, we are using many telephone transformers. Our incoming telephone lines to the Spokane office—we have six or eight of them—are all equipped with telephone transformers; the main generating plants are equipped with telephone transformers; on such substations as I have outlined we provide a stool, which is nothing more or less than a high-tension insulator with a platform on top of it, and a man stands on that when he is telephoning.

I think I have answered our chairman's remarks with reference to a substation on a truck, in talking on Mr. Hunt's remarks.

Mr. Pope is laboring under a misapprehension; the Washington code does not require two men in each station although it is true that a bill was introduced at Olympia last winter calling for two men. The reason, so far as I know, for requiring two men in each station had no reference to safety; it was simply to make jobs. Mr. Hayward touched on the question of two

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operators in a station. We have one station in Spokane, which is our high-tension substation where our lines come in from our outside plants. At that station we have one operator on shift only, and the other operator is in his house (they both live in cottages provided for them alongside the substation) so that if help is required and the operator on duty is able to go for the help he can get it. There is no reason why he should ever have any trouble so far as the electrical arrangements are concerned, as that station is made about as " fool proof " as it can be made. The switches are all remote control, and the disconnecting switches are handled with long insulated rods, and the only case where he might require help would be in case he should faint or be taken sick; so far as any question of electrical risk is concerned that is practically eliminated. Mr. Hayward's remarks with reference to the reliability of service over one line I think are well taken. We supplied the Coeur d'Alene country from 1903-1908, I believe it was, on one line. We went in there when all the developed mines were running either on water power or on steam; since the day we started giving service I do not believe there has been one single piece of steam apparatus going into that district. The few steam plants that they had, if they are not in the junk pile, are ready to go; the water power of course they use, because that saves them a little money, but very little; so I think we have demonstrated that you can give service over one line that will satisfy a mining community. I am very glad indeed to know that Mr. Hayward endorses my views on the three-phase versus the single-phase transformers.

I am going to dodge Prof. Karapetoff's suggestion of taking up the question of delta versus Y, it is too big; we could argue all day and never get any result. I will say this, that our prime reason for adopting Y on the high-tension side is the fact that we reduce our strains on all the apparatus by grounding our neutral at the generating plants. We have a stress due to 34,700 volts from line to ground. I believe that that is worth a whole lot, and of course doing that prevents a delta delta connection. We do not use any resistance in our ground connection. We started ten years ago with grounds all through our system; experience has rather tended to indicate that is wrong and we are now removing the grounds everywhere except at the power plant; at the power plant we expect to keep our grounds, and we expect to have them dead grounds without any resistance; if a line is in trouble the sooner we know it the better, because we can get out and fix it.

I was very much interested in Prof. Karapetoff's statement about the visit to the manufacturer who told him how to arrange his telephone lines to give the indication in case of fuse blowing. I wish I had known that manufacturer, because it would have saved us a whole lot of worry.

The rate for power in the Coeur d'Alene district is $3 per

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kv-a. per month, based upon the maximum kilovolt-amperes used in each month, and in addition a charge of one-half cent per kilowatt hour for the kilowatt-hours used in each month. For a one-year contract there is no discount; two-year contract 10 per cent; three-year contract 15 per cent; five-year contract 25 per cent; the Bunker Hill & Sullivan Concentrating Company is working on a five-year contract, so that from that the rate can be figured.

**J. H. Lighthipe:** What is the length of time required to install an oil transformer, to replace the burned-out one; that is to dry out and fill with oil? You spoke of the kv-a. capacity. What capacity charge is taken for them on the kv-a. or the kilowatt capacity?

**J. B. Fisken:** We take the assumed voltage of 2300 and measure the amperes. As to the time required to change the transformer in the case of a burn-out, it is a little hard to answer because it depends altogether where the burn-out is. In our more improved substations we have spare transformers. Now, in the Coeur d'Alene country we can get one into service in about three hours.

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DISCUSSION ON "ELECTRIC DRIVE IN MACHINE SHOPS" (FAIR) PHILADELPHIA, PA., OCTOBER 13, 1913. (SEE PROCEEDINGS FOR OCTOBER, 1913.)

*(Subject to final revision for the Transactions.)*

**Harold Goodwin, Jr.:** The speaker discussed the advantages of the individual drive and the cost of operation; but he left out apparently the cost of initial installation.

In some cases it has been said that individual drive would cost from three to four times as much as group drive, and there was no apparent advantage obtained by the individual drive. In the case of spinning mills, recommendations have been made by motor manufacturers to install individual drives and some have installed them and some have kept on with their old steam engines, rather than invest in the new drives.

In mills where almost all the machines are the same and of moderate power consumption would it not be advantageous to use group drives rather than go to individual drives?

**R. L. Lloyd:** In reference to the same subject mentioned by a previous speaker, we frequently find in soliciting business for central station service, especially where a different form of motive power has been used, that the question of initial expense is a very vital one. And where a complete installation of individual drives would be of some advantage, the tremendous additional expense over group drive plays such an important part that the consumer finds it is best to give up some of the operating economy. It is always a question of final results, and where the fixed charges are enhanced too much, resultant economy may suffer.

**William W. Benson:** There has come to my notice recently the case of a manufacturer of fine goods for men's wear, who having observed that 64 looms being operated by motors on the central station power in his vicinity, made better goods and approximately 5 per cent greater quantity per loom, than 100 looms on power from his corliss engine, has decided, whenever possible, to shut down his engine and operate on central station power.

**C. O. Mailloux:** The extent to which the motor drive has been adopted in Europe seems to me to be evidence of its utility and advantages. The Europeans are extremely careful in their capitalization investments, and their amortizations. They are apt to be very conservative in making new capital investments, and before making any changes they generally make sure that there are not other better ways than the ones under consideration. They only make a change when they find a manifest advantage in doing so.

The electric drive appears to have made great progress abroad. I visited several European works during the last three months, and I was struck by the absence of belting. I find a marked tendency to the adoption of the direct drive in textile establishments. The most modern establishments are all electrically driven, every weaving or textile machine having its own electric

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drive. Among the model establishments which I visited recently was an automobile engine factory. I noticed not only that the machinery was modern, of very perfect type, well arranged, but I noted especially that it was all electrically driven.

**Charles Fair:** Generally speaking, the drive and machinery in a textile mill differ so greatly from that of a machine shop that I would prefer not to discuss drives for textile mills at this time. You will, however, find that considerable increase in production has been made throughout New England in the textile mills, due to the large number of individual motor drives in use. The ideal drive for large and moderate sized machine shops, production and maintenance considered, would be a combination of alternating current and direct current, the alternating current for constant speed machines and the direct current for adjustable speed machines. Individual versus group drive would be a question of cost of installation, the size and kind of machine involved and the product manufactured. The advantage of driving large machines with individual motors is generally recognized, for obvious reasons. With small machines there are many factors that would enter into the determination of the question of individual versus group drives. Cost of installation only considered would mean group drive; production considered would mean certain small machines, tool grinders, drills, etc. placed for convenience among large individually driven machines. These would necessarily be individually driven, as would small machines placed at intervals for convenience on assembling floors or where light conditions were essential or where dust, grit, noise or objectionable fumes might make it desirable to remove a machine out of the reach of a line shaft. Modern requirements of machine tools often call for such complicated performances that the use of adjustable speed motors offers the only practical solution. Where a considerable number of small machines are used for duplicate work and where they are closely bunched, it might be desirable to group them and drive with one motor instead of using individual motors. I say "might be" because I know of cases where group drives are not desirable even under these conditions.

Much of the noise due to the use of high speed raw-hide gearing, is due to the shrinking of the raw-hide. I have seen cloth gears transmitting 50 h.p. and under with comparatively little noise at the rate of 4200 ft. (1280 m.) peripheral speed. There are numerous cases where herring bone gears are transmitting power at speeds of 5000 ft. (1524 m.) and even higher.

Due to the increased cost of production as much as to any other factor, the tendency is more and more towards getting out of a tool its maximum production. To protect a tool to the extent of cutting down production is usually expensive protection. Except in rare cases a machine should not slow down

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on account of the load increasing. Machines should be chosen with the idea that they will do the work expected and in the shortest possible time and they should not be handicapped by lack of power.

In conclusion, I would quote Mr. Gano Dunn, who, in discussing line shaft versus motor drive some three years ago, concluded by saying that " the electric motor would drive the line shaft from the machine shop just as surely as it had driven the horse from in front of the car."

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DISCUSSION ON "INDUSTRIAL SUBSTATIONS" (LIVERSIDGE), PHILADELPHIA, PA., OCTOBER 13, 1913. (SEE PROCEEDINGS FOR OCTOBER, 1913.)

*(Subject to final revision for the Transactions.)*

**W. C. L. Elgin:** I think Mr. Liversidge has covered many of the important points in relation to substation design, but I have gained the impression that he has paid too much attention to the question of space economy. Although the size of the apparatus readily lends itself in that direction, I think there are many bad designs because too much attention has been paid to obtaining the smallest possible space for the apparatus.

I know of three substations designed for 2000 kw. each; and in examining them, I was impressed with the fact that the principal and only question considered, was apparently to find a place for each piece of apparatus and then to build a wall around it. These substations were only about 20 feet square; and after installing the apparatus there was no room for making repairs. In order to properly inspect any part of the plant that might become defective, it was necessary to go outside of the building, and look into the substation through a window. For this reason, these substations had to be abandoned.

I think the pictures showed that where there was rotating apparatus, reasonable space was allowed, but that the space was smaller where merely static apparatus was installed. In the static substation of 4000 kw. the entire apparatus was installed in a space 30 feet by 10 feet. That space, of course, was ridiculously small. In the next two or three years, I think you will find that this substation will have to be enlarged or otherwise altered.

The cost of the building is relatively small in comparison with the importance of the reliability of service and also with the total cost of the service. The real estate and building costs are practically small items.

One other point in the paper is that of enclosing all the apparatus, especially the high-tension apparatus. I think it should not be enclosed completely, but that partitions, some of which may be made of glass, should be placed around it; or an open space should be provided, of a size sufficiently large to permit of an examination of the apparatus, but small enough to prevent the operator inserting his hands, and making accidental contact. Another advantage of this is that you can locate any trouble in the particular compartment in which it occurs; but if completely enclosed, the smoke will travel from one place to another.

There was another point of which Mr. Liversidge did not speak, and that is the danger, in these cases, from water. It seems to me that substation apparatus should be so designed that it would operate even if completely immersed in water. There has always been a great objection to having water around an electrical installation. I know of a case where a 2400-kw. substation was partially submerged for twenty-four hours and

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continued in operation during this entire time. That is an accomplished fact; and we now know that we can operate under these conditions.

I wish to make a plea for more space in substations, instead of space economy.

**P. M. Lincoln:** Mr. Chairman, I have not much to offer, but I wish to commend the careful thought given in Mr. Liversidge's paper to this question of substations and their design. There has been a great deal of thought given in the past to power stations, but substations and the use of the power therein has been more or less neglected. The substations of the past have partaken somewhat of the nature of "Topsy"—they just grew. I think we are to be congratulated in having someone like Mr. Liversidge, who has given careful attention to this subject, give us the results of his study in a carefully prepared paper such as this.

Mr. Liversidge said the three-wattmeter method was used in some stations and the two-wattmeter in others. Why is that?

What is the method for measuring the maximum demands? Has the maximum demand method of charging come into general use?

Those are some of the questions which occur to me at this time in connection with Mr. Liversidge's paper.

**John Mathews:** I have noticed that in many of the cases which Mr. Liversidge cited, they use single-phase transformers rather than the polyphase units. The cost of the polyphase is less than the cost of the single-phase unit and the space occupied may be less.

Were there any other features which made the decision in favor of the single-phase unit?

**G. W. Brooks:** I note in Mr. Liversidge's paper that in the majority of cases installations include two banks of transformers, one of these being spare. It would seem that this is a greater expense than necessary, as reliable service can be secured by the installation of four single-phase transformers, one transformer to be held as spare. This saves the cost of two complete transformers.

In metering power when service is given through two incoming feeders, is it not practical to install current transformers in each of the two incoming lines and connect these transformers in multiple to the same watt-hour meter?

Is it considered desirable to install overload relays on each incoming line feeder where reverse energy relays are used and protection is secured by overload relays on oil switches serving apparatus connected to substation bus?

**W. C. L. Eglin:** Thinking over some of the remarks I made earlier this afternoon I thought I might possibly have given the impression that I was criticising that portion of Mr. Liversidge's paper regarding space economy. What I wanted to say when I made my statements, was that the apparatus lends itself to

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space reduction so well, that that feature is generally abused and the space cut down very much below reasonable limits.

**P. V. Stephens:** This paper is one of great interest to designing engineers, and there is one point not strongly emphasized in comparison with these other points which have been enumerated. That is, that in addition to the space and the general design, etc, the controlling idea in the design of the substation, especially the industrial substation, should be the continuity of the service that is to be supplied. In other words, in larger installations you will find that this is of prime importance, and it is one of the reasons why a great many of the companies prefer to have their own power and pay more for it, than to run the risk of being shut down because they are depending on one or two feeders.

If you will present to them a lay-out which will guarantee a continuity of service you will go a long way toward getting them to use central station service. One way is to have as many sources of supply as possible. Have at least two feeders from the company's power station to the users, and a two-bus substation system has many advantages. By providing two-way switches on the feeders you can switch on to either bus. This gives a flexible arrangement and greatly decreases the possibility of a shut-down, thereby providing a continuity of service which is a very important factor in supplying power to industrial plants and especially very large plants.

For instance, in the case of a ship-repair plant where a great ship is on the dock to be repaired, and there are heavy overhead and docking expenses all the time the ship is in dry-dock (and to this expense must be added the loss of business), a condition often necessitating a day-and-night job, you can readily imagine what the cost must be in the case of unnecessary delay on an important ship where the steamship company is deprived of its service. You cannot then afford to have a shut-down; and it was on such a proposition in Brooklyn, New York, where I had to design an electrical installation of that kind, that it was necessary for us to give them a positive guaranty of no shut-down on their extensive equipment, and for the last six years they have run continuously without loosing a day or night on an equipment of 3500 h.p. in electric motors. But they would have had trouble on four different occasions due to carelessness or accidents, if I had not had the two-feeder, two-bus system in operation.

**Charles Penrose:** In further extension of the remarks of the previous speaker I ask Mr. Liversidge whether in the design of such substations use cannot be made of bus-sectionalizing switches on single-bus systems in order to insure continuity of service, rather than the necessity of a *double-bus* system such as has been suggested by the immediately preceding questioner? For these reasons: the double-bus lay-out incurs double initial expense, which is undesirable from the point of view of investment, re-

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quires increased upkeep and adds to the complexity of operation. The latter is one of the important points which Mr. Liversidge has tried to bring out in his paper this afternoon, namely, the desirability of freedom from those complexities which may spell "trouble" in the operation of the substation.

In regard to the particular interest which Mr. Liversidge's paper has had, at least for me, I would say that it was my good fortune in connection with Mr. Albrecht to be asked by Mr. Liversidge to assist in a small way in the preparation of the paper, and that it has occurred to me more than once what great wealth of material for a paper is offered at this time by the industrial substations already in service in this country. Mr. Liversidge, because of the limitation of space and time, had to restrict his remarks to some 12 stations, which are in operation in different American cities.

The possibilities that are open for further investigation of industrial substations throughout the country are almost limitless, even if consideration is given only to the larger installations. The engineering characteristics of industrial substations have reached the point where the proper design of these plants is comparable to the design which enters into the installation of large central station substations.

But Mr. Liversidge has drawn clearly the line of demarcation between what apparatus should be installed in industrial substations, and what apparatus may not be permitted because of lack of space and complexity of arrangement.

A contrast of the 12 substations which were discussed shows many points of difference in the voltages, phase and frequencies of the sources of supply. The several plants included static, synchronous converter, or a combination of both kinds of equipment. All of these points could only be dwelt upon fully in a very long paper.

The point I want to bring out is that the subject is one of very great importance due to the tremendous development we now have in electrical installations in consumer's premises, where, as I have already said, you may have a substation whose equipment is comparable in many cases to that of the largest substations in those of the larger central station systems.

**Harold Goodwin, Jr.:** The previous speakers have laid emphasis on the question of continuity of service, particularly with regard to emergency services. Yet I should not like this discussion to go down as unqualified endorsement of emergency services. It may be necessary in some cases, but in other cases the expense might not be warranted. Even if the central station puts it in, the consumer has to pay for it in the end, and this militates against low rates.

The necessity for emergency service depends largely on the value of continuity of service. No one has been able to evaluate this, but the ratio of cost of current to total operating expenses has been found a fair indicator of it. It would be interesting if this

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ratio could be added to the data on each plant mentioned in the paper.

**H. P. Liversidge:** In reply to the points brought out by Mr. Eglin relating particularly to the subject of space economy, would say that I thoroughly agree with him in the matter of greater space for substation lay-outs. The point that is desired to be emphasized is rather that the space allotment is usually a minimum, due primarily to the fact that the question is often decided before the engineer is asked to consider the installation of the equipment. In most cases this space is too small to be at first considered, and only after considerable effort on the part of the operating company is enough space given to permit of a satisfactory installation. It is quite evident, therefore, that such a condition usually results in a lay-out occupying the extreme minimum of building space.

Replying to Mr. Lincoln's question concerning the two-wattmeter or three-wattmeter method of measurement, I might say that while the two-wattmeter method is perfectly correct, there are practical considerations which arise in operating conditions where the three-wattmeter method is to be preferred.

Referring to the installation of spare transformer units, I would say that, under certain operating conditions one additional transformer will be sufficient for replacing any of the regular operating transformers in case of repairs, etc. Where an interruption of service due to transformer breakdown would be serious, however, it would seem better practise to install a complete duplicate installation of transformer units and switch board equipment.

The subject of continuity of service is one that is of interest to all. The question of duplication of switch and busbar equipment to insure greater reliability of operation, however, under certain conditions is doubtful. For normal capacities, modern switchboard construction has reached that state of development where the danger of breakdown in the busbar or switching equipment need not be seriously considered. It would seem, therefore, that the best installation is that which embodies simplicity in its arrangement rather than the duplication of equipment to insure continuity of operation, in the event of switchboard failures. Where continuous operation is necessary, proper installation of section switches in the busbar and busbar taps will obviate the necessity of complete duplication of buses and switch gear and will permit of a ready examination of the operating equipment.

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DISCUSSION ON "RELATION OF PLANT SIZE TO POWER COST" (LINCOLN), PHILADELPHIA, PA., OCTOBER 13, 1913. (SEE PROCEEDINGS FOR OCTOBER, 1913.)

*(Subject to final revision for the Transactions.)*

**Harry Archer Hornor:** Mr. Lincoln has properly stated in the introduction of his paper "that most engineers are ready to admit without argument that a large power plant can supply a given power service as a part of a general power supply business more economically than a plant merely equipped for special manufacturing business." Therefore it is obvious that we should look to other than engineering considerations to find the motives which prevent the prospective customer from purchasing his power from a central station.

The author of this paper presents two arguments that may be urged against the central station method of supply. The first of these arguments, namely the question of the transmission and distribution of power, may easily be dispensed with because of the increasing number of central stations in congested communities, as well as the development in the art of very high potential distribution over long distances. Factories today are rarely placed without the zone of a central station. The promotors of an industrial venture would take into consideration the question of the advantages of such power supply in selecting a site for their plant. I doubt very much whether the central station would have been given as much consideration say ten or fifteen years ago.

The author's second argument in favor of the isolated plant, namely, the use in most industrial companies of steam, must indeed have careful consideration. This argument seems to be the last one which is of direct importance to the engineer. Many industrial plants not only require steam for heating purposes throughout their plant and offices but also employ it in various parts of their manufacture. No doubt the use of steam in this way is extremely uneconomical, and no doubt other forms of energy could be just as well applied. Furthermore, it may be purely because the steam plant is there that steam is so used. Nevertheless the fact that a conversion to some other form of energy must now be made, causes the owner to consider very carefully the cost of this substitution. We see how quickly the problem changes from that of engineering into commercial economics.

Mr. R. S. Hale in a paper read before a joint meeting of the American Institute of Electrical Engineers and the American Society of Mechanical Engineers held in Boston, February 16, 1910, points out a condition which I dare say would be found in a majority of isolated plants, namely: whereas the central station would figure its cost of power too high the isolated plant would be apt to figure its cost of power too low. This problem would be an extremely easy one and very definite of solution if the isolated plant only manufactured one kind of

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power. As a matter of fact the large manufacturing concern, especially those doing a varied business, must equip the plant with many different forms of power. Mr. Lincoln has pointed out that this is exactly the place where the central station can aid because the diversity factor is large and the generating units would naturally be in proportion, making their first cost relatively high. On the other hand the isolated power plant would be under one operating force and under the same accounting system which would make it difficult in most cases to determine the individual costs of power without a very elaborate system of bookkeeping.

The manufacturing company with which I am connected uses four different kinds of power for its construction purposes, namely, electric, pneumatic, hydraulic and steam. All these forms of power are generated in the same power-house and with the same operating force. It would not be possible to definitely determine the unit cost of any one of these without an elaborate installation of instruments, a special piping system and a particular system of bookkeeping. Let us take the electric power alone: Two double-current generators are daily providing the electric power. These units are rated at 500 kw. and carry a regular load throughout the day of about 600 kw. or 20 per cent overload. They are therefore operated normally at good efficiency as far as the generator is concerned. There is also installed one 500-kw. direct-current generator. This generator is also used for what might be called peak lighting load. The switchboard operator throws the two double-current generators into the distributing system in the morning, shuts them down at noon, places them in service after the noon hour, and shuts them down at quitting time, except in the event of the plant working overtime. This switchboard operator is as a matter of fact an oiler. Since there has been installed a voltage regulator he has no more duties as regards the running of the electric plant than those above outlined. If central station energy was substituted for the electric plant, there would be no reduction in operating force.

Let us consider the problem in another way: The electric power consumed seems to bear a relation, something like 20 per cent, of the total power with the exception of steam. As we would not reduce our operating cost, and could only look for a reduction at the coal pile, the immediate commercial question that would be asked is, would we reduce the amount of coal purchased per year by twenty per cent, and how much money would this represent when we include the amount paid by the year to the central station? For the plant in question, and with the data that is available I am of the belief that there could be no commercial consideration given to this proposal unless the central station could supply electric energy so that no more operating expense to the customer would ensue, and that the cost per kilowatt-hour would be less than one cent. If the plant used

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alternating current it would only be necessary to install an industrial substation equipped with static transformers. This would answer the first part of the question. As it happens, approximately one-half the load is direct current, generated at 230 volts, and the other half is two-phase 25-cycle, 200-volt, alternating current. This would necessitate either the conversion of the present plant or the installation of synchronous converters. The power house as now designed would not permit the installation of any additional apparatus, so that parallel operation with the present machinery would only be possible by the erection of a separate building involving a separate operating force.

The next consideration is then, the substitution of electricity for producing all the power, so that the present power house could be completely dispensed with and an electrical substation substituted. This involves a number of interesting considerations into the detail of which it is not possible to fully enter. Briefly, this comprises the question of rotary hydraulic pumps; rotary air-compressors and the question of heating. This latter, though possible of accomplishment by means of electricity, will, I think, be generally admitted to be an expensive substitution, although as Mr. Lincoln has stated the small plant does not reach a point where it pays to install certain economical devices for the production of steam, yet on the other hand there are certain practical economies which can be introduced by which wastes of various kinds, though not entirely eliminated are very much reduced. This makes it problematical in the minds of the owners of such plants, to maintain their plants up to a point where either developments compel a change, or depreciation is so great that the apparatus can no longer sustain the demands put upon it.

It may appear from the foregoing that this is an argument for the isolated plant and against the central station. Such is in no sense the intention. It is rather an endeavor to find the reason which prompts men who own isolated plants to retain them in preference to the purchase of power. The central station may be a little to blame in not making special efforts in this direction.

Granted that they have at the present time accomplished much, I cannot see but what it depends greatly upon whether they wish to accomplish more. If the central station, as Dr. Steinmetz recently stated in an address before the Franklin Institute this month, can find an off-peak power load that does not cost them the installation of more apparatus and additional operating expenses, it is safe to say that the central station could sell its power at even as low a rate as mentioned by Mr. Lincoln in his illustration of diversity factor as shown by the United States Reclamation Service in the Idaho Irrigation System. But if, as we have recently heard it proposed, the central stations take over the power supply to railroads for the electrification

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of surburban lines, I do not see but what the central station will be required to install and operate more apparatus, because this load will undoubtedly strike the peak, as the busy people will be going to and from their work at the same time that the station will need to supply its peak load.

This is an interesting subject because it is such a large one and so many different factors enter into every side from which you view it. Although steam central plants have shown a wonderful reliability as well as flexibility, it has not been very long ago that a friend of mine in the northeastern part of this country very seriously considered annulling his contract with a water-power central station, and installing a plant of his own. I believe, however, that it is generally recognized to-day that such central stations, subject by the elements to an interruption of service, must parallel their water turbines with a steam plant, because of this uncontrollable consequence.

I notice that Mr. Lincoln in his paper did not touch particularly upon this point, and I suppose he did not because such eventualities are not so frequent. It is nevertheless a very important motive in any manufacturing concern whose product depends entirely upon the supply of electric current.

As a summary I should deduce the following:

First, the promoters of any new manufacturing venture would today consider the location, and operation of their industrial plant so that central station power could be used. This would be considered in their estimate of first cost, expense of operation, and in their original design.

Second, for those owners who are now operating isolated plants supplying various powers including steam, convincing reasons must be presented whereby they may abandon their present plant entirely and economically purchase their power.

Third, I believe the principal motive underlying the retention of the isolated plant is due to commercial economy rather than to engineering principles.

Fourth, I believe that the central station in its development will overcome all obstacles and reduce the number of isolated plants.

Fifth, I also believe that in the case of very large vessels that a central station adapted for this special service will be installed, and that requisite power will be delivered both for the driving of the vessel and for the operation of her auxiliary machinery.

**W. C. L. Eglin:** Mr. Horner seems to take up one or two questions on the other side. There is a fourth point that occurred to me while Mr. Lincoln was reading his paper, and that is, the depreciation of any apparatus. The consumer invariably has his mind fixed on the efficiency shown by his apparatus when first installed and tested; and he still believes it is operating at the same point of efficiency after several years of use. The central station company generally finds that it pays to discard such apparatus and install more efficient apparatus. That is

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verly clearly shown in all the larger stations; whereas with the individual owner of a small plant, some particular change in his business or the extension of the business to the point where the plant becomes too small for his needs, would be required before he would think of abandoning it.

The next thing is the inertia to be overcome. Take the case of the tungsten lamp: It is three times as efficient as the carbon lamp, yet there are three times as many carbon lamps sold today as there are tungsten lamps. The people are not installing as many tungsten lamps as they should, and it will take from three to five years to educate them to do so. In Europe you will have a task trying to find a carbon lamp. You see them, it is true, but you see many more tungsten lamps than carbon, while in this country you will see more carbon lamps than tungsten.

It is only a matter of time before the central station must be extended to the point where its service will become practically universal.

That is the real objection to the substitution of electrical service from the central station—you must have a property large enough to be able to afford to "scrap" apparatus, even to the extent, sometimes, of removing the entire plant investment from your books. It is hard to get the ordinary manufacturer to throw out his plant and "forget about it."

**P. V. Stevens:** I ask Mr. Lincoln for my own information, and possibly for the sake of others, this question: The discussion or treatment in this paper has been apparently referring to steam plants, and the majority are familar with the conditions met in such plants, but assuming the advantage of the large central station over a small station is 10 per cent, I would like to know what percentage would represent the advantage in the operation of oil and gas plants where the fuel is relatively cheap.

**C. O. Mailloux:** This paper discusses the general case very comprehensively and intelligently. When we come to special cases, certain modifications may be necessary in the reasoning and in the conclusions, as the author has himself pointed out, We all agree, for example, in regard to the general statement that the economy of a plant will be a direct function of its size. There are, however, considerations which often argue in favor, and demonstrate the superiority, from a financial standpoint, of a small individual plant—the so-called "isolated plant."

My experience with isolated plants covers a period of over twenty-five years, and it is so diversified that I cannot now give more than a general summary of it. As consulting engineer, I have had, during that period, to deal, in some technical capacity or other, with perhaps a thousand isolated plants, large and small. In more than half of these cases, I have had charge of the design and installation of the plant, and in a number of cases I have also had charge, for a time at least, of its operation.

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I have also had occasion to make reports in regard to the feasibility and economy of isolated plants in hundreds of cases. In the latter cases, the question was gone into most thoroughly; a very careful, honest attempt was made to get at all the facts and figures bearing on the case, in order to reach the true and correct answer as to whether the plant would pay or not. In many cases, the answer indicated that the plant would not pay; but in many others it showed definitely that the isolated plant was warranted. I will only refer now to those instances where there was absolutely no chance for the central station to replace the isolated plant.

A very interesting case was that of a large sugar refining establishment in Brooklyn, in which a boiler plant of about 10,000 h.p. was rendered necessary because of the immense amount of evaporating to be done incidental to the sugar refining operations. This large boiler plant would have to be there anyhow. The same boiler room force and the same facilities would be necessary whether the electric current supply required for lighting and power came from an isolated plant or from a central station.

At the time this plant was designed, the question of electric current supply received careful consideration, and it was soon made obvious that the cheapest and most practical way would be for the establishment to produce its own power, by generating steam at high pressure, say 150 lb., and reducing this pressure to that which is required for evaporating, namely, from 7 to 12 lb., by passing the steam through a simple engine designed to operate under a back pressure of 7 to 12 lb. Now under those conditions, a simple engine would not be particularly economical, as we know, but looking at the matter from the standpoint of thermo dynamics, and considering the amount of energy abstracted from that steam in being thus "throttled" from 150 lb. pressure down to about 10 lb. pressure, while passing through the engine cylinder, one finds that the steam loses only a very small percentage of its total energy, (the actual theoretical loss is only about 3 per cent for the above conditions); and yet in falling by expansion from 150 lb. to 10 lb., it is capable of generating a great amount of power. The plant was installed and was a great success. It has been running more than 15 years, developing somewhere between 1500 and 2000 h.p., through engines operating direct-connected dynamos which supply electrical energy sufficient to operate the lighting system and for all the electric motors of various sizes required in the different buildings. In a case like this the cost of fuel and boiler room attendance are reduced to an insignificant amount. The only items that enter materially into the cost of the electric power are the cost of engine and dynamo attendance, and the fixed charges on the cost and also the maintenance of the engines, generators, dynamo leads and switchboard; and considering the large output obtainable from the plant, it is apparent that the cost of electrical energy per kilowatt-hour must be very

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small. That concern is one of the few in New York City that can afford to use electricity for cooking. It literally has electricity to burn. An electrical cooking installation was put in which has been in operation since the plant was started, and which serves daily for cooking the lunch for a large force of men, composed of the heads of various departments. My recollection is that the cost of electric current was somewhere around 2 or 3 mills per kw-hr. It would, of course, have been impossible for any central station plant to compete with such an isolated plant.

There are many other cases where the isolated plant proves to be cheaper for the consumer than the central station current supply. I have found this to be true in scores of cases, as in large office buildings, where steam heating is required during many months. Mr. Lincoln says that no heating is required for more than half the year. My own experience leads me to a different conclusion. In these latitudes, one must figure on heat being required in a building for at least seven months. Most of the time during that period, the fuel consumption which is properly chargeable to the electrical service when high pressure steam is used, and the cylinder of an engine is employed as a throttling valve to bring the steam pressure down to three or five pounds, is small because, as already seen, the energy abstracted from the steam by that throttling process is very small. Even assuming that there may be a certain time during the 24 hours of the day when one must use steam that is not chargeable to the heating system, yet the total cost of the coal and of the boiler room attendance chargeable to the electric service in the winter months is very small. This matter has been investigated by me, or under my direction, in many scores of cases. In some instances we have been able to corroborate the conclusions of our investigations. There were cases where the current had been supplied from a central station and return was made to the isolated plant. In other words, we have had cases where the same building has been operated under the same conditions, both by current from a central station and by current from its own isolated plant. We have also had cases where the steam for heating as well as for power was taken from the central station in New York which furnishes steam to consumers through underground mains. We have been able to make comparisons of cost in instances where an abundance of good and reliable data was available to enable us to check up the results and conclusions very carefully. One interesting instance was the building in which my office was located for a number of years. In this case the isolated plant, after being operated for a certain period of years, was stopped. Electric current was taken from a central station and steam for heating was taken from the underground steam mains. The total cost of the service proved to be considerably higher than expected, and eventually a return was made to the isolated plant, which has since then remained in operation.

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A careful study of the facts and figures, taking into consideration every factor bearing on the case, including depreciation, obsolescence, rental value of space, and all like conditions, showed that it cost the building less to produce its own supply of electricity and steam than to take it from the street mains.

I think that Mr. Eglin's remarks in regard to lamp economy have an important bearing upon this situation. It now seems possible that we shall be able to reduce the lighting load of a plant to a great extent with lamps giving a candle power with ½ watt. Under those circumstances, the electric load, especially in buildings where electric current is used almost entirely for lighting, will be greatly reduced. While this does not make much difference in the winter months, yet it will make considerable difference in the summer months, because the expenses which are fixed, such as the cost of labor, interest on plant, etc., then become relatively large and increase the cost per kw-hr. materially. Under those circumstances, the isolated plant, while still effecting a saving during the winter months, might represent a loss during the summer months. I therefore expect that the improvement in efficiency of incandescent lamps will help to bring about the gradual elimination of isolated plants.

I am in accord with the feeling that the number of isolated plants will go on diminishing. It seems to be in harmony with the nature of things, and with the principles which Mr. Lincoln has so clearly set forth in the first part of his paper. I cannot quite assent to the proposition that they can be all eliminated at the present time. It is my belief that there are many, indeed thousands of cases, where the isolated plant is still cheaper than the central station. I would not say, however, that the time will not come when we may speak of an isolated plant as having been relegated to the museum of ancient things.

**M. G. Lloyd:** As one engaged in a weekly endeavor to demonstrate the desirability and feasibility of central-station service I have been much interested in Mr. Lincoln's paper. He has demonstrated his main thesis, viz., that power can be generated at less cost in a large plant than it can in a small plant, but as he grants in the last two pages of his paper, that is not all there is to the question of installing central-station service.

I am sorry we have not more figures on the question of what the cost of distribution is, as I believe it to be a much more important item than the author has indicated. I think I remember that a representative of the Baltimore central station at one of our former meetings made the statement that the investment in the distribution plant in that city was greater than in the generating plant. In Chicago this is undoubtedly true and the distribution system there has probably cost 30 or 40 per cent more than the generating plant. Consequently the fixed charges on this portion of the investment are greater than the fixed charges upon the investment for power house and there will also be an operating expense for distribution which will

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cover the power loss in cables and maintenance cost for this portion of the system. This results in an important item of the total cost which the isolated plant does not have to include in its computation.

One of the standard arguments for the isolated plant is the economy of combining the use of steam for heating and for power generation. Mr. Mailloux has already shown that there are cases where that is sufficiently advantageous to over-balance any advantage the central station may have in other respects. Mr. Lincoln has rather weakened his argument on this point by limiting the period during which buildings require heating to six months; in my territory (Chicago) heating is required for fully eight months. While heating is not actually required every day during this period it is necessary to have steam up and ready to turn on in case of a sudden turn to cold weather. It is true that the load curve for heating is, however, not coincident with the load curve for power, but that does not affect the question of cost so much as the point of whether the peak loads coincide. Mr. Lincoln claims that the heating load in many instances falls off entirely before the power peak comes on between 5 and 6 p. m. This is not true of office buildings, which must be heated well into the evening.

I should like to take exception to one minor point in the paper where diversity factor is referred to. In order to have a diversity factor of unity the author claims that the loads must be proportional at all times. I do not think that statement can be upheld because even though the load curves may be entirely different in two plants having the maximum in each case at the same time there is no diversity since the generating equipment must be sufficient to supply that maximum and the diversity factor will be unity, although the load factors of the two plants are entirely different.

Central-station solicitors realize that if their business depended only on the three main propositions brought out in Mr. Lincoln's paper they would have no difficulty in getting all the customers that were solicited. Other points have to be met, however, and while it may not have been within the province of Mr. Lincoln's paper to discuss these, still they must be considered with respect to central-station service. His arguments are getting stronger every day, owing to the ever increasing size of the central station, and its units, which are now up to the point of 20,000 to 35,000 kilowatts. The central-station man can make his case stronger in every instance where he has the best of the argument if he realizes fully the arguments upon the other side and is free to admit that there are cases where the central station cannot compete with the isolated plant.

**C. O. Mailloux:** I think that the previous speaker overestimates the importance of the increasing size of the central station units. The total cost of delivering the service from the central station is not made up of the central station cost plus fixed

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charges, but is made up of the total central station cost plus the cost of delivery. Now the cost of delivery, it happens, is very much greater than the cost of producing the energy. The most that can be expected as the result of increase in size of the units is an economy of a few mills per kilowatt-hour. If the cost of electrical energy at the bus-bars in the central station is, let us say, 55 mils per kw-hr. we may be able to get it down to 45 mils or even to 35 mils. There is an "asymptotic" value somewhere, which is probably between three-tenths and four-tenths of a cent. To this must be added the cost of transmission and distribution. The further economies realizable must be effected mostly in the cost of distributing the electrical energy supplied to the consumer, which is never less than 0.5 cent to points near by, and it may be two, three or four cents to remote points.

It seems to me that we cannot hope for much from the increased economies resulting from the increased efficiencies in the central station. In a case where the bulk of the cost is for electric power (for electric elevators, ventilation, etc.), the conditions will not be more favorable to the central station, but more likely will be less so. The conditions which may make a great decrease in the load of the isolated plant will arise especially in cases where the bulk of the service is for lighting.

**J. P. Jackson:** Many plants that you would consider competitive in any way, may be so small that it would not pay to put in feed-water heaters, etc. But I judge that with any plant so small that it would not need such auxiliaries, there is no question but that it would be more economical to go to the central station for power. Certainly very small primary power generation units are as a rule very undesirable, when central station power can be obtained at suitable rates.

I would like to emphasize Mr. Eglin's statement about the depreciation in figuring out the cost to an isolated plant. The specialist emphasizes the necessity of improving everything. I imagine the man who puts up the money in the plant sees very dimly that the actual plant is decreasing or depreciating due to the improvement of the art. His plant is running all right, and he does not like to be told that it is depreciating on account of advance in the art.

There is another thing I believe it is worth while to mention specifically and that is the lucid, clear statement of these subjects which our friend Mr. Lincoln uses. He has an extraordinary way of putting things, so that a layman, like some of us, can understand what he is saying. I believe if the engineers would confine themselves to a simple, clear intelligible statement of the principles of science and engineering, that engineering would advance with greater rapidity than otherwise.

Finally, permit me to say that I am on the side of the central station. I believe the central station is bound to be the great source of power in the world; but I also believe with Mr. Mail-

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loux, that each case must be studied out on its merits, and no general statement of the facts should be accepted. Mr. Mailloux is right, that buildings having lighting, heating and other loads to carry might be different in their relative conditions from others.

**G. J. Blum:** It seems to me that the discussion has brought out a point worth considering and that is that the central stations while trying, so to speak, to get nearer to their customer, are in reality getting further away from him. I refer to the concentration of generating equipment in a very few very large power houses which in many cases are located at an average great distance from the points of greatest load, thus entailing high fixed and high maintainance charges on distribution equipment.

A reasonable increase in the number of generating stations so located in reference to load centers as to reduce line losses and cable troubles to a minimum and to make possible an alternative selection at the substations, especially the large industrial substations referred to tonight, in case of trouble on any particular feeder, would in the speaker's opinion make much more remote the possibility of any interruption of industrial service dependent on central station supply. The matter of steam heating service from such central stations would further suggest itself as a possible source of revenue.

I think it is along these lines that thought might be directed by those men responsible for the most profitable operation of the central station.

**P. M. Lincoln:** The point is well made by Mr. Hornor and Mr. Eglin, that the central station not only must show economy in serving a new customer but that often in the case of an existing isolated plant, the central station must have charged against it the fixed charges on the plant that is displaced by the use of central station power. It is an endeavor to show a saving after a scrapping of the old plant which breaks the back of the central station.

The paper I have prepared necessarily deals with generalities, and contemplates the conditions necessary to compete when no isolated plant exists. When we deal with the conditions of an isolated plant already built, the margin in favor of central station power is much reduced and sometimes wiped out.

Mr. Eglin mentions the fact that carbon lamps were scarcely seen abroad while very frequently used in this country; and I looked at the lights used in this room and I find they are carbon lamps. Here is a case in point where carbon lamps are in use, and where tungsten lamps would undoubtedly save a considerable amount.

Mr. Stevens has asked a question as to the possible competition between central station plants and isolated plants that use oil or natural gas for fuel. The best answer I know of to that is to point to the scarcity of such oil and gas plants. Theoretically the Diesel engine or the gas engine can do better than the cen-

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tral station steam plant in the matter of thermal efficiency. However, the handicap against them in other directions is such that they have made comparatively little headway.

Mr. Mailloux cites a case where the central station plant would have no chance at all. His sugar refinery required large quantities of steam for the vacuum pans for evaporating, and there was consequently a large boiler plant, and the small percentage of steam that was taken in generating the power made the power cost comparatively slight. It takes very little more heat to turn out steam at 150 lb. pressure than it does at 15 lb. and the power that can be obtained in throttling down from 150 lb. to 15 lb. is a by-product which costs practically nothing. In that case I do not think central-station power would stand a ghost of a show.

I note my estimate of the time during which heat for buildings is required is questioned. My estimate was based on conditions as they exist in my own house. I start my furnace about October 15th and stop about April 15th. If I should count from the time it is first started to the time when it is last used, it might be somewhat more than six months; but there are warm fall days and warm spring days when the furnace is not required. Now the requirement for heating in the usual building in the main covers about the same period of time. There is a further fact which I did not emphasize in my paper, that the maximum heat requirements for zero weather are tremendously greater than the average. This fact entails a very decided additional difficulty in using the same steam for both heat and power.

In answer to the comments of Mr. Mailloux and other gentlemen, let me point out the first of the requirements I set forth in the last page of my paper; I there call attention to two reasons why central-station power might not be used to supply all of the electrical service within legitimate reach of their distributing systems. The first of those reasons is, that the rate offered by the central station does not bear a suitable relation to the cost of the service to be supplied. I believe that the increased use of central station power that will surely come as time goes on will reduce its cost very considerably from what it has been in the past.

Mr. Lloyd mentions the fact that the cost of distributing central station power is very considerable, which is true. In one case I figured the distributing cost ran from 60 to 70 per cent as much as the cost of the power itself. But that cost enters into fixed charges only. The distributing system "eats no coal" except what may be due to the losses therein, which are comparatively small. The additional cost of central station power on account of distribution is not sufficient, in general, to justify the isolated plant.

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## DISCUSSION ON "TUNGSTEN LAMPS OF HIGH EFFICIENCY—I AND II" (LANGMUIR AND ORANGE), NEW YORK, N. Y., OCTOBER 10, 1913. (SEE PROCEEDINGS FOR OCTOBER, 1913.)

*(Subject to final revision for the Transactions).*

**John B. Taylor:** I would first like to make a few remarks, to give the audience a few moments' time in which their eyes may become accustomed to the great difference in brilliancy between the filaments they have just been looking at and the enlarged projected image, which, perhaps, will have a brilliancy of something in the order of one-millionth part of the brilliancy of the lamps at which you have been looking.

I can testify to the satisfaction that this lamp gives in projection work after using the lamp with a projecting microscope and also for photo-micrographic work, particularly color photography. The steadiness of the lamp as compared with an arc lamp, either hand-fed or automatic, leaves the worker absolutely free to give all his attention to the subject or specimen and the photographic plate. A switch turns on the lamp and the light source is always exactly in the same position. Its intensity will always be the same, and repeated exposures will give similar results. The color value is good, as it is almost as white as a carbon arc. In projection work half of the light is thrown backward, but a large portion of this can be conserved by the use of a reflecting mirror, properly placed so that the reflected image practically coincides with the source of light. The projection arrangement I have here will show this. This reflector arrangement is of no value in the case of the carbon arc, as the electrode casts a shadow backwards. As shown in Fig. 1, the reflected image is inverted with respect to the direct image.

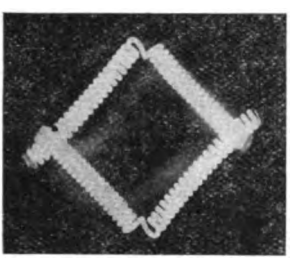

FIG. 1

(Mr. Taylor then threw the projection on the screen.)

I ask Dr. Langmuir if he can tell us anything of the ratio of the resistances of the filament hot and cold in the nitrogen-filled lamps. This may be an important factor when the lamp is switched on if there is a momentary overload of fifteen or twenty times normal.

**John W. Howell:** Dr. Langmuir has made an analysis of the residual gases in tungsten lamps, and has devised an apparatus for the making of qualitative analyses in determining the five constituents in one cu. mm. of gas. That is a marvelous achievement. During all the years we have been working on incandescent lamps we have been interested in residual gases, we have known they were there, and we had a general idea what they must be, but we never had the initiative to try to measure them in quality and quantity as Dr. Langmuir has done.

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The first summary of Dr. Langmuir's, on page 1914, reads as follows: "The efficiency at which tungsten lamps may be profitably run, is limited principally by the blackening of the bulb." Dr. Langmuir should have drawn that statement more carefully, so that it would refer to large lamps. It is true of large lamps, but it is not true of the small lamp. Forty-watt lamps and all smaller standard lamps blacken so little that they break before the blackening becomes objectionable and their useful life is their total life. These lamps constitute over 75 per cent of all lamps sold. In large lamps the efficiency is limited by the blackening of the bulb. There are two reasons for this. The small lamps have thin filaments. If these filaments waste away by evaporation, and one spot is hotter than the other, the hottest spot will waste fastest, and it will break there. This wasting will break a thin filament in shorter time than a thick filament, consequently the thin filaments break before the evaporation has proceeded far enough to blacken the bulb. We test in the laboratory all 40-watt lamps at 0.9 watts per candle. Their total life at 0.9 watt per candle is about 400 hr., and at the end of that time they are not blackened sufficiently to render them objectionable or make us take them down. Large-diameter lamps will live longer. Another reason why lamps with thick filaments blacken more than those with thin filaments is that thick filaments are used for high candle power lamps and in these lamps, for practical reasons, the bulb area is not nearly so large relative to the candle power or filament surface as in thinner filament lamps, and as the evaporation from a filament is proportional to its surface, these larger lamps with less bulb surface per unit of filament surface would get blacker in a given time. This difference in bulb surface in relation to filament surface is very great and causes large lamps to become useless by blackening before the filaments break.

As to the second paragraph in Dr. Langmuir's summary, I have recognized for some time that there are three different kinds of blackening in a tungsten lamp, and that the ordinary blackening which proceeds very slowly and is uniform throughout the bulb is caused by the evaporation of the filament. I believe that same thing of carbon lamps, and if you will refer to the TRANSACTIONS of this Institute for March, 1894, you will find a paper written by Prof. Anthony on "Incandescent Lamps Containing Heavy Gases." Prof. Anthony concludes with the statement that the blackening of the carbon lamp is caused by the evaporation of the filament, and Prof. Elihu Thomson, and Prof. Robb, of Hartford, and Mr. Doane agreed, in discussing the paper, that the blackening was due to this cause.

In discussing that paper I said that there were two kinds of blackening, one was due to evaporation, I believed, and the other was not. Now, the other kind of blackening, which I thought was not due to evaporation, is always irregular in its deposition on the bulb. In carbon incandescent lamps we fre-

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quently met an irregular blackening which we call mottling, and mottling always occurs in a lamp which has a defective vacuum. Of course, there are different kinds of defective vacua, but only a few kinds of defective vacua that produce that mottling. There is one condition which always produced a mottled discoloration of the carbon lamp, and that was in the case of lamps which we made at one time, in which we put a little clay in the anchor clamp to hold the filament. These lamps were always discolored irregularly and with mottling. That same mottled discoloration is found in tungsten lamps. This lamp (exhibiting lamp) illustrates a mottled lamp, but the discoloration is not black. It is a lightish discoloration, caused by oxygen, by air. That is a mottled discoloration. I believe that any residual gas in a lamp which attacks the filament will produce a mottled discoloration.

The other kind of blackening in lamps is due to water vapor. We have believed for a good many years that the gas which comes from the glass of the lamp as it is heated was water vapor, but we did not know it. Dr. Langmuir proves it and now we know it. It is impossible, I think, to exhaust out of a lamp with a mercury pump all of the water vapor which comes off the glass when you heat it. The only way in which we can take it out is by the use of phosphoric anhydrid.

Water vapor in a carbon filament lamp does not cause the lamp to blacken as in a tungsten filament lamp. Here are two tungsten lamps (exhibiting lamps) that were made in the spring of 1907. When we made these lamps we exhausted them together in the same way. After they were exhausted and sealed up as finished lamps, I took one lamp and with a gas torch heated the bulb hotter than it had been heated in exhaustion, and then the two lamps were put up on a life test and burned over night, and the result of one night's burning was that the lamp that had been heated to drive the water vapor off the bulb into the lamp was black the next morning and the other one remained perfectly clear. We discovered also that when we heated the bulb during exhaustion the water vapor was sufficiently removed so it did not come out any more afterward.

Away back, about 1890, there was a lamp put on the market called the novak lamp, a carbon lamp with one mm. of bromine in it. The lamp was not commercially successful because the bromine had, as nitrogen has, bad effects and good effects, but in that carbon lamp the bad effects were greater than the good effects, and the result was a disadvantage and the lamp did not live.

At that time I made a lot of experiments on the effects of gases in lamps. I made measurements with four gases, nitrogen, hydrogen, bromine and chlorine. The lamps I used were first exhausted with a very good vacuum, and then increasing amounts of each one of these gases, separately, were admitted to the lamp, and the change made in the specific consumption of the lamp

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by the cooling effect of the gas was noted, and these changes were plotted in a curve which showed the effects of any amount of either one of these four gases in the lamp. At first it was impossible to make a lamp which would burn well with any gas in it. It was only when we realized the absolute necessity of dryness in the gas that we succeeded, but when we got these gases absolutely dry, neither one of them had any ill effects on the lamp. I mean as to making it black; but they all cooled the filament and this cooling effect is what we measured.

The effect of water vapor in a carbon lamp is to render the filament sooty and black. This makes it a very excellent radiator of heat, so that it is cooled by radiation to such a degree that the candle power falls away down, and yet the bulb remains clear.

**Farley Osgood:** The question that interests the operating engineer is, what is the hope of the development of this lamp in small units? As Mr. Howell has said, 75 per cent of the lamps used are in small units.

**J. E. Randall:** You have had here an exhibition of this new development and a demonstration of the operation of these lamps during a period of a few moments. I presume that I am the last person in this hall to have seen any lamps of this kind operated in the Research Laboratory at Schenectady. I saw some lamps there today and identified them as those that I saw operating under the same conditions a number of weeks ago. They have been operating continuously since the first time I saw them. Therefore, I think we can say that this development is successful. The development will be beneficial because it marks a long step in the energy efficiency of a device that is notoriously inefficient.

If we grade the quality of lamps by the initial efficiency, that is, filament temperature at which they will show a certain performance, the so-called nitrogen lamp will take a very high rank. If we establish as a standard of performance, the initial efficiency at which a lamp will develop 90 per cent of its theoretical candle hours during one thousand hours of burning, candle maintenance and mortality both considered; and if, on this basis, we call the raw carbon filament lamp 100, the various types will rank as follows:

| | |
|---|---|
| Raw carbon filament lamp | 100 |
| Treated carbon filament lamp | 119 |
| Gem filament lamp | 149 |
| Tantalum filament lamp | 206 |
| Tungsten filament lamp | 359 |
| I have not complete data for the new lamp but it surely would have a rating of | 600 |

We should not consider these developments as extending the lives of lamps. Their success should rather be gaged by their energy saving. The real advantage of any improvement in the incandescent lamp is utilized by raising efficiency rather than by prolonging life.

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The way for the new lamp was to a great extent prepared by the production of ductile tungsten. Methods of shaping the drawn tungsten wire into helical coils have been so developed that they are of signal assistance. Accuracy of control of wire diameter, which, one may say, has almost reached perfection, will doubtless add speed to the commercial development of this latest lamp.

**William McClellan:** I ask whether Dr. Langmuir in closing will say a word about frequency in connection with the lamps, especially low frequencies, with low-voltage lamps. Is there any difference between that and the ordinary tungsten lamp?

**Irving Langmuir:** Different frequencies of alternating current?

**William McClellan:** Yes. The point is that the ordinary carbon lamp at 25 cycles, low wattage, does not flicker so that it can be noticed. When you come to the tungsten lamp it flickers considerably. I am interested in knowing whether the new type of lamp will be different from the tungsten, or practically the same.

**John W. Lieb, Jr.:** The question naturally arises, what is going to be the effect of this great movement forward in lamp efficiency on central station service, and what is its effect going to be on the general question of improvements of efficiency and life of incandescent lamps? Undoubtedly these new lamps will necessitate a revision of our criteria which have prevailed hitherto as to what should be considered as the useful life of the lamp. Useful life, as we know, has been established in accordance with general agreement that when the lamp has depreciated in candle power to 80 per cent of its initial value the useful life of the lamp has ended; it has reached the "smashing point." Now, with these new developments in the lamp, and the increased efficiencies which have been attained, it will be necessary for us to modify our figure, or at least give it new consideration in the light of the electrical data which these new lamps present. The central stations have long ago passed that period when they could afford to exhibit any fear as to the ultimate result of an improvement in the art, in any direction in which the art might progress. This new development will help to reach that consummation which we have all been hoping for, that the electric light will reach the humblest home and be as easily accessible to the humblest of our citizens as kerosene.

Another question which is raised by these lamps is, what will become of the arc lamp? I think it is no empty prediction that the arc lamp under the impulse which this new development produces, will achieve further advances to put itself in line to continue the contention with its new competitor.

**M. G. Lloyd:** We are told that the nitrogen is at about one atmosphere pressure. I ask the reason for using that particular value. I should like to know whether it is considered objectionable to have a higher pressure than one atmosphere inside the bulb.

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**H. M. Fales:** Telephone companies are interested in the success of the tungsten lamp for street lighting purposes. The present carbon arc lamps produce variations in the lighting circuit of such frequencies that serious disturbances are often caused inductively in telephone circuits located on the same street. With tungsten lamps this is not the case. The disappearance of inductive disturbances in telephone circuits has already, in a number of cases, been traced to the substitution of tungsten lamps for arc lamps.

**Farley Osgood:** I might suggest that Dr. Langmuir in closing say a word about the stability of these lamps. Our friend Mr. Lieb has indicated the possibilities of it for arc use, which is very interesting to operating engineers.

**Irving Langmuir:** The difference in brilliancy, pointed out by Mr. Taylor, between the inner and outer portions of the helix as thrown on the screen, is due, I think, principally to reflected light from the inner sides of the turns. In other words, the conditions in the interior of the helix more nearly approach those in a so-called " black body " furnace. The difference in temperature between the inner and outer part of the wire may be approximated by calculation, and is found to be less than 10 degrees, an amount to small to account for the large difference in brilliancy.

It might at first sight appear that the imprisonment of light by reflection back and forth between the adjacent turns of a helix causes a waste of light energy. In a sense, this is true, but since the heat energy is also imprisoned to nearly the same degree, the power needed to heat the filament is decreased in about the same ratio as the light. The efficiency at any given temperature is therefore not seriously affected by the helical winding. Experiments confirm this.

Mr. Howell's criticism that the failure of small lamps is due principally to breakage and not to blackening is, I feel, quite correct. In writing the paper I had in mind lamps of 40-watt size, or larger. Although under the usual operating conditions the failure of 40-watt lamps running at normal efficiency is, as Mr. Howell points out, rarely due to blackening, yet our experiments have shown clearly that as soon as the specific consumption of such lamps is lowered to about 0.8 watts per candle, the bulbs blacken relatively rapidly and the candle power often falls to 50 per cent of the initial candle power, or lower, before failure occurs.

I did not mean to claim in the paper that we were the first to find that water vapor in lamps is injurious, or to suggest evaporation as a cause of blackening. I know that the presence of water vapor has been considered extremely harmful, in both carbon and in tungsten lamps, from the early days of their manufacture. I have pointed out that evaporation as a cause of blackening was one of the theories often applied to the blackening of lamps.

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# THE FEASIBILITY OF AN A. I. E. E. HANDBOOK

## REPORT OF THE HANDBOOK SUB-COMMITTEE

HAROLD PENDER, CHAIRMAN

THE Handbook Sub-Committee of the Electric Power Committee was created at the instance of President Mailloux to consider the feasibility of the Institute's compiling a handbook to be issued to its members, and also to present the idea for discussion, in order thereby to determine the feeling of the members at large regarding such a project. As pointed out in the remarks by Mr. Thomas, Chairman of the Engineering Data Sub-committee, the question presented to the Handbook committee was that of the collection and presentation of *exact* data, which would include formulas, physical constants, or other commonly accepted standards. The suggestion that the Institute bring together such information is not entirely new, but there has been little recorded discussion upon the matter.

There have been a few instances of other technical societies in the country issuing to their members hand books or manuals of a nature somewhat similar to that suggested above. One example is that of the Society of Automobile Engineers, which has compiled a handbook of technical data of special value in the design of automobiles and their accessories. This book is issued in loose leaf form and is sent to all members of the Society. As regards a similar book for the use of Electrical Engineers it would appear that there are few points which could be treated in an Institute handbook which are not already covered to a greater or less extent in the existing handbooks of publishing houses. Some of the material in the existing books might be expanded for the use of electrical engineers engaged in special lines of work, but it is doubtful whether the probable limited sale of such " unabridged " tables and date would warrant their publication.

The National Electric Light Association issues a book known as the " Electrical Solicitors Handbook." This book is made up chiefly of cost data and catalog information. It is intended primarily for the use of solicitors for electric light companies.



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The N. E. L. A. has also issued an "Electrical Meterman's Handbook." There would not seem to be a great call for the Institute to compile a book of such specialized character as these.

Another instance of a handbook issued by a technical society is the "Engineering Manual" which will be issued shortly by the American Electric Railway Engineering Association. It is understood that this book will contain information on the existing standards and recommended practices of the association as contained in the past transactions of the society. To some extent this work appears to be similar to the standardization rules of the Institute which are now being revised by our Standards Committee. The A. E. R. E. A. manual will evidently be more extensive than the Institute's "Standardization Rules" because in electric railway work it has become customary for committees to standardize many dimensions and practises, a policy which can scarcely be adopted in the general field of electrical engineering.

Such considerations have convinced the majority of the members of the Handbook Sub-committee that the project of the A. I. E. E. compiling and issuing a handbook of technical data is neither especially desirable nor is it practicable.

One member of the committee believes that the Institute can do valuable work in exerting its influence upon the publishers of the present handbooks to combine their efforts into the production of the "Ideal" electrical engineers handbook. It is questionable, however, whether the commercial interest involved would consider such a proposal, although no one can deny the inconvenience to the user of having two or more handbooks covering practically the same ground, as is now the case, due to commercial competition.

During the discussion of the committee upon the possibility of an Institute handbook, two suggestions were made which appear worthy of presentation for discussion. The first of these was to the effect that the information contained in the present volumes of the TRANSACTIONS might be condensed for presentation to the members. At first glance, such a step appears desirable, for there is a vast amount of valuable information contained in the Institute papers which is lost to most of the members two or three years after the paper is presented, because of the time required to discover its existence. If the data regarding electrical engineering facts and methods contained in the TRANSACTIONS could be condensed into small space, the book

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would be exceedingly valuable. The members of the committee undertook to try this condensation of the material upon selected topics, but found that the work which would be involved in a systematic condensation of the papers covering a number of years, would be enormous. To carry out this work in a reasonable time would be beyond the powers of a committee. To carry out the work by salaried officers would cost so much that it has not appeared to the members of the committee that the project was feasible. The difficulty of getting at the information contained in the TRANSACTIONS upon a particular topic has also been lessened to a great extent by the two volumes of indexes of the TRANSACTIONS from 1884 to 1910, the second of which has just appeared.

Another suggestion was that the Institute might compile volumes of papers upon certain subjects, such as transmission lines, traction, telephony and telegraphy and the properties of material. These volumes could contain papers selected from those presented before the Institute and also certain papers presented before other societies in this country and abroad. Such a compilation would place in handy form a large portion of the most valuable contributions on those special topics during recent years, and would be of great value to the members of the Institute who are interested in the topics which might be covered. These books might be published by the Institute itself or an arrangement might be made with one of the large publishing houses similar to the special arrangement made with the McGraw Publishing Company in 1905 for the publication in one volume of the papers on high-tension power transmission presented before the Institute under the auspices of the High-Tension Transmission Committee from 1902 to 1905. This book and a companion volume containing the papers on high-tension power transmission presented before the International Electrical Congress in St. Louis in 1904, were well received and another volume of Institute papers on the same subject might be compiled to advantage in the near future.

## DISCUSSION

**H. M. Hobart:** A member of an Institute committee could not put any better efforts into the work of contributing a section to an Institute handbook than he could in the case of a handbook brought out by an independent publisher. The members of Institute committees are usually in their daily professional activities so burdened with tasks of an exacting nature

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that it is impracticable for them to make contributions requiring hundreds of hours of their time.

However they can make contributions of much greater value in their capacity of members of a committee of a body devoted to the advancement of the interests of the electrical engineering profession. In this capacity they can so direct and influence large activities as to increase the efficiency of these activities and they can also precipitate useful dormant forces into activity.

I consider that the Institute could with entire propriety employ its influence in such directions as would be most effective in bringing into existence a handbook of electrical engineering out of all proportional superior to any which has yet been published, or is likely to be published in the immediate future. The plan would be to invite representatives of the leading publishers to a conference at which the endeavor should be made to bring about an understanding of the following kind. There are probably not more than half a dozen publishers in America who issue engineering handbooks which enjoy a wide sale. Three or four out of this half dozen publishers each issues a handbook of electrical engineering. No one of these handbooks is at all satisfactory, nor is there any prospect that the new editions about to be issued will be to any very great extent better than the editions now on the market, though doubtless there will be decided improvement. It is chiefly because the market is so divided up by the three or four handbooks that there is not a sufficiently great turn-over for any one handbook to yield the profit essential to expending more than a certain sum in the preparation of the handbook. Suppose, for instance, that each of the four leading handbooks of electrical engineering enjoys a circulation of 5000 copies. Few electrical engineers buy more than one of these handbooks. Probably the total issue of 20,000 copies of the four handbooks is taken by 15,000 engineers. Each of these 15,000 engineers puts up with a very inferior article. If the rival publishers should agree to leave the field of publishing an electrical engineers' handbook to one of their number, then the undertaking could be made so much more renumerative in view of the larger edition which could be published as to permit the improving of its quality 200 or 300 per cent. Even then it would still fall far short of the ideal. But it would be so much better that the total sale would probably run to some 50,000 copies as against 20,000 copies representing the combined sale of the four inferior handbooks. Certainly if the Institute sub-committee could by means of such a conference or series of conferences, bring about this result it could consider that it had rendered a very great service to the electrical engineering profession.

The question naturally arises whether it could be reasonably expected that so successful a result could be brought about. There would be no hope of this unless each publisher could be satisfied that his own interests would be served. It is believed

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that this would be the case. The publisher who should be allotted the electrical engineering handbook would agree to limit his hand book-publishing activities to that particular undertaking. Some other publisher would be allotted the mechanical engineering handbook, the third the civil engineering handbook; the fourth a handbook dealing with naval architecture and marine engineering, and so on. In bringing about this undertaking it would be of advantage if the committee could be reorganized into a larger committee which should have in its membership representatives of other societies such as the American Society of Mechanical Engineers, the Society of Naval Architects, and others. It would even be reasonable (although it should not be necessary) that the various engineering institutions concerned should stand prepared to subsidize such undertakings, in the event that it could be absolutely demonstrated by the publishers that their interests would be jeopardized by the plan in question. Probably a better plan would be some scheme of insurance so that the engineering institutions should be prepared to come forward and make up the return to such an amount that the publishers should incur no risk of decreased net profits. In equity, however, such an arrangement ought to include one whereby any profits above a reasonable amount should be set aside and should go toward decreasing the price of future editions, or else still further improving their quality.

It might even be considered within the realms of probability that by sufficiently prompt action any publishers who may be at present concerned in undertakings relating to new editions of electrical engineering handbooks could be induced to reconsider their plans and substitute for their rival editions a single electrical engineering handbook of vastly superior quality. It is quite probable that it could be demonstrated that in spite of the expense which may already have been incurred in the preparation of their new editions, the same net profits could be insured to the publishers by this re-arrangement of their plans.

In connection with the other project to which allusion is made in the sub-committee's report, I am of the opinion that while the sale of the republications of the power transmission papers was not large, nevertheless the interests of the electrical engineering profession were greatly promoted by their republication. I consider that the time is auspicious for adding to these two volumes two or three more volumes on the same subjects. I believe, however, that instead of confining the undertaking to papers presented before the American Institute of Electrical Engineers, there should, by arrangement, be included the most notable and valuable papers on these subjects which have been read during recent years before other institutes, such as the Institution of Electrical Engineers of Great Britain, and the National Electric Light Association. These papers should be accompanied by the discussions which occurred at the times of their presentation, as such discusssion are often of more value than the original

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paper. It is believed that a volume could with advantage be added to this set every two or three years. I do not wish to indicate that there would be large sales for such volumes, nevertheless I believe that editions running well on toward 1000 copies could be readily disposed of in the course of a few years from the date of publication, and that an edition of such a size could be disposed of at a reasonably low price without incurring any loss. Here again would be a good opportunity for co-operation in the sense that the American Institute of Electrical Engineers could arrange with the Institution of Electrical Engineers of Great Britain that one of them should carry on this scheme with respect to papers on high-tension power transmission, while the other should render a similar service by taking up, say, central and substation design and operation. I am of the opinion that especial value would attach to an undertaking of this sort which should deal with electrical railway papers. Much valuable work in this field is buried in the transactions of various societies and congresses and it could with great advantage be brought together in a series of volumes. The chronological order should be observed in the preparation of these volumes, and papers originally read so long ago as in the nineties, would be of much value if resurrected in this way. Instead of confining the undertaking to the papers which have been presented before the American Institute of Electrical Engineers, it would be preferable to include a large number of other good electric railway papers which have been read on other occasions. Amongst these occasions are, for example, congresses such as those which have been held at St. Louis, Turin, and various other places. Many valuable railway papers have been read before small societies, such as the Rugby Engineering Society, and the Liverpool Society. I do not propose that all electric railway papers coming in these categories should be included, but that the entire collection should be rigidly scrutinized and weeded out until a residual group of very high value should remain. After once bringing such a set of volumes down to the present time, a volume should be added every couple of years or so.

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# RECORDING DEVICES

BY CHARLES P. STEINMETZ

ABSTRACT OF PAPER

The author calls attention to the importance of keeping records in electrical systems and points out that proper records can be secured only by automatic recording devices largely because of the uncertainty of the personal element in times of accident or stress. The three types of recording devices in general use are those having a revolving disk, those using an endless tape or photo-film, and multi-recording device on which no record is made of normal operations and on which the record sheet moves only when a record of abnormal occurrences is being made. The revolving disk machines produce such condensed records that a sequence of rapidly fluctuating events cannot be distinguished, while the curve drawing instruments, if the tapes were run rapidly enough to show all the fluctuations, would produce records of such enormous length that they would be impracticable to operate commercially. With the multi-recorder the record is made in a very condensed and handy form and its accuracy in respect to time is very high, so that the sequence of events recorded can be checked within a fraction of a second. The latter instrument, therefore, is adapted to produce minute and accurate records of all phases of station operation.

WHILE the keeping of records is essential in any business, it is especially important in the operation of electrical systems, and thus records have always been taken of voltage, current, power, of the time of starting or stopping generators etc. in electrical systems.

Perfect reliability however can be secured only by automatic recording devices.

For instance, where it is the duty of the station operator to keep constant voltage, the voltage record made by noting down the voltmeter readings at constant periods of time would probably show uniformity, while an automatic recording device may show bad fluctuation between these times. A protection against neglect or carelessness of taking records, and a check on the operating force, is afforded only by automatic recording devices. But especially when things go wrong, when accidents happen, and the necessity of action interferes with careful ob-



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servations, the human machine more or less breaks down and only automatic devices are reliable in recording the events.

Automatic recording devices are therefore extensively used: Revolving-disk recording voltmeters, ammeters, thermometers, steam flow meters etc.; curve drawing instruments; the oscillograph.

In the revolving-disk recording meter, a 24-hour, or 12-hour record is made on a circular chart. The shortest time interval, which can, under industrial conditions, be accurately noted on these instruments is not much less than a quarter of an hour. Where the quantity changes slowly, as the temperature of a room, a clear chart is given. Where, however, more rapid fluctuations occur, as with current and often with voltage, the chart shows only a broad blur, and neither the individual variation nor the sequence of events can be seen, but merely the maximum and the minimum values estimated.

Curve drawing instruments, in which an endless tape moves with greater or less rapidity, in front of the recording pen, are used for records of more rapidly changing events, as current, voltage, speed, acceleration of a rapid transit train cycle, etc. But to take a continuous record of an interurban railway substation by a curve drawing instrument moving sufficiently rapid to show all the fluctuations, would be feasible only in special investigations; but the enormous length of the record would exclude it in commercial operation.

One of the most rapid recording devices is the oscillograph, and its use has been of material assistance in electrical development, for instance in giving information on momentary short circuit currents of alternators, on the performance of circuit breakers and other problems, upon which information could be derived in no other way. But the taking of a continuous record of station operation by oscillograph obviously is out of the question.

While automatic recording devices are necessary in the normal operation of electric systems, they are still much more essential under abnormal conditions, when things go wrong, and accidents happen. Usually no serious difficulty exists in designing apparatus to operate satisfactorily under normal conditions; also no serious difficulty exists in operating a system under normal conditions, but to meet the abnormal changes of accidental conditions is the serious problem of the electrical designer and of the station operator.

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We really know relatively little of the abnormal conditions which are met in electrical operation, and most of our knowledge is rather theoretical, representing what might happen; but exact information of what actually happens is extremely limited. When some accident happens, whether it be the failure of a transformer, or the shut-down of a big system, usually an investigation is made, reports called for, and the witnesses cross examined. But the information gleaned from these examinations is practically always unsatisfactory and incomplete. Frequently no trained observer was present, or so many things happened almost simultaneously, that most of them could not be observed. The circumstances are very unfavorable for exact observation. The necessity of immediate action excludes close observation and almost always excludes immediate

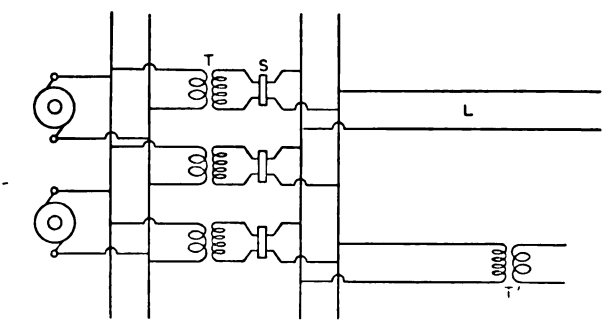


FIG. 1

noting of the observations, so that the record must be based on the memory of the observer, which is not very reliable in times of excitement. The personal element also comes in, the natural tendency of avoiding personal responsibility for the accident. The sequence of the events, which is all important for the understanding of their cause, is rarely noted in the excitement, and thus such examination hardly ever definitely fixes the cause of the accident, without the necessity of very extensive guessing of more or less questionable reliability. It is, however, of the greatest importance to the operator as well as the manufacturer of the apparatus, to know exactly what happened, so as to guard against its recurrence, and to fix the responsibility.

For instance; in a large high voltage transmission system, partly illustrated diagrammatically in Fig. 1, a big transformer *T* in the generating station, a high-tension switch *S* in the gen-

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erating station, and a transformer $T'$ at the end of a branch line are destroyed. At the same time a flashover occurs on the transmission line $L$.

Postmortem examination of the transformer showed numerous arc burns on coils and on the tank, and the coils badly deformed and bent out of shape. Questioning of the operators elicited the information, that lightning has been frequent during the period preceding the accident. One operator believes to have noticed static in the station for some time before the accident. It is suspected that numerous short circuits have occurred in the lines during the weeks preceding the accident.

This information is altogether too meagre to find out beyond doubt what actually happened. We can only theorize what may have happened, for instance:

1. An arcing ground occurred on the line $L$, producing moderately high frequency—a few thousand cycles. This lasted for some time, possibly hours, until the high frequency broke down somewhere, either by electrostatic heating of the insulation, or by the continual impact of the oscillation. It broke down to ground in the station transformer $T$, and thereby caused a short circuit through transformer $T$ and line $L$. The high tension switch $S$, in attempting to open this short circuit, failed due to the excessive current and the superposed high frequency oscillation, burned up and so created a dead short circuit at the transformer terminals. The mechanical magnetic forces resulting therefrom in the transformer, moved the coils. The shock of the short circuit broke down the transformer $T'$ at the end of the branch line.

2. Numerous flash overs had occurred during the preceding weeks in the transmission lines, resulting in heavy short circuits. While the transformers were strong enough to stand occasional short circuits, the short circuit stresses were so enormous, that continual short circuits gradually impaired and finally broke down a transformer $T$. This resulted in the destruction of the circuit breaker $S$, the failure of the second transformer $T'$ etc.

3. Lightning entering the line $L$ started a high frequency cumulative surge in the transformers, producing spark discharges between the coils. The same or another lightning stroke flashed between the lines, caused a short circuit, resulting in the destruction of the circuit breaker. The spark discharge in the transformers finally led to short circuit, which distorted the transformer coils.

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4. An internal oscillation in the transformer, due to entrance of high-frequency lightning, or resulting from an arcing ground on the line, caused spark discharges in the circuit breaker, leading to its destruction. The short circuit resulting therefrom, moved the transformer coils and brought them sufficiently near to either end of the tank, to cause arcing over, with the resulting destruction of the transformer.

Numerous other combinations of the phenomena could still be devised, to account for the accident, for instance, the transformer $T'$ at the end of the branch line may have broken down first, and the accidental arc may have produced the high frequency, which damaged the circuit breaker and main transformer, and flashed over the transmission line, etc. But whether the trouble started with a high frequency oscillation in the transformer, or resulted from a high power short circuit, or from lightning, or from an arcing ground on the line, or from a combination of two cases, as high frequency oscillation and short circuit, cannot be obtained from the available sources of information. Neither can it be determined, whether the transformer was mechanically too weak to stand a short circuit, or whether it was weakened by frequent short circuits combined with high frequency disturbances. It is, however, of importance to the manufacturer to fix the responsibility, and to know whether the transformers are mechanically too weak and should be made stronger, and correspondingly more expensive, or whether and what additional protective devices should be developed. And it is of still greater importance to the operating companies, to take such steps as will insure reasonable reliability of operation.

If automatic recording devices would show what happened and the sequence of the happenings, whether the trouble started with lightning, or with an arcing on the line, or a line short circuit and how this originated, or a transformer surge in the generating station or the branch line, etc., then in most cases the phenomena could be exactly determined, and with reasonable certainty precaution against their recurrence taken. Also, less difficulty would usually be experienced in fixing the responsibility on the manufacturer of the apparatus, or on the operating engineer, or on *vis major*. As it stands at present, the transformers are rebuilt with greater mechanical strength, and damping devices against transformer surges installed, and it is "hoped" that the phenomena against which these guard,

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were the causes of the trouble, but we cannot possess the confidence that the same will not happen again, and if similar troubles do occur again, it merely means that some of the other various possibilities were the initial cause of the trouble, and that the remedy would lie in the installation of an arcing ground suppressor, or in grounding the neutral, or in disconnecting the grounding of the neutral, or in reducing the sag of long spans to eliminate the swinging together of the lines, or in adding another disk to the suspension insulators, or in better weeding out defective insulators by high frequency testing, etc.

Numerous such instances could be given. Thus, in underground cable systems, breakdowns occur frequently in groups, or practically simultaneously, and it is difficult to determine which cable started the trouble. For some time, often days, troubles with feeders may have preceded the break down, and if properly recorded, would explain its cause and so give a greater probability of guarding against its recurrence etc.

The difficulty or impossibility of getting complete and exact records of what happens in electrical systems, and of the sequence of the events, is the most serious limitation, at present, to providing protection to such systems.

Automatic recording devices thus are of the greatest importance for the safety of operation of a system, especially where reliability is important. However, in case of trouble, the sequence of events commonly is so rapid, within seconds or less, that such devices must be capable of recording within fractions of seconds. The dial instruments, like the revolving-disk recording meters, therefore, are out of the question, as they show everything within a few minutes as simultaneous. Curve drawing instruments would have to run the tape rather rapidly. If we assume that 50 records are needed, and allow between $\frac{1}{8}$ and $\frac{1}{4}$ in. per second as the minimum, about 15 miles of tape would be unrolled per day, and to look all this over to see the records, obviously is impossible, especially when it is desirable to go back for weeks to see what has preceded. With phenomena like lightning, where several strokes may occur in one minute, and then no record for weeks or months, obviously any recording device with continuously moving tape is impracticable. Where records are made at more or less infrequent intervals—sometimes, as with circuit breakers, at fairly regular intervals, and sometimes, as with lightning discharges, at very irregular intervals—an instrument in which the tape

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does not continuously move, but, as in the typewriter, move only when making a record, is essential.

To give reasonably complete information on the station performance under normal as well as abnormal conditions, records are required of the closing and opening of every circuit breaker, of the operation of the lightning arresters, of the appearance and duration of high frequency in the lines, of grounds and short circuits, possibly of excess currents, of overnormal and subnormal voltage, frequency, etc., etc. Considering then, that even a small station may connect two or three lines, and each line has three phases, and a separate record of each phase is necessary, it is obvious that a considerable number of records is needed. With a stationary record sheet, moving only whenever a record is made, 50 records can easily be taken on the same sheet, and a 50 point multi-recorder thus appears as a convenient unit. In such a device, a sensitivity of at least $\frac{1}{4}$ to $\frac{1}{2}$ second is desirable, so that phenomena following each other at intervals of $\frac{1}{4}$ second or more, are separately recording, while everything which occurs within $\frac{1}{4}$ second appears as of the same time. Such high sensitivity is desirable to get the sequence of events which to the observer may appear simultaneous, as the break down of a number of feeders etc. At the same time, such great rapidity of action requires a powerful mechanism and when considering that the operating mechanism must be capable of working very many thousand times without failure by wearing out, the problem in the development of such an automatic multi-recorder was rather a difficult one. Also, when a record comes in within less than $\frac{1}{4}$ second from the preceding one, while the record sheet is still moving in receiving the previous record, the second record would blur, and this difficulty thus has to be overcome by retarding the second record until the taps have come to rest.

On such a multi-recorder print, one record point should be reserved for recording standard time at fixed intervals, thus giving the time correction of the clock work which operates the recorder, so as to make it possible to record the sequence of events occurring almost simultaneously in distant stations and noted on different multi-recorders.

A description of this instrument is given by Prof. E. E. F. Creighton, in the A. I. E. E. TRANSACTION, Vol. XXXI, 1912, p. 825.

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## Discussion

**Chas. L. Clarke:** Dr. Steinmetz has referred to the taking of continuous records by the oscillograph or other curve drawing instrument, in which a photo-film or a paper tape is reeled off at a constant speed to maintain uninterrupted the time-element of the record, and he has in general called attention to the obvious impracticability of using an apparatus of this character adapted for recording events that may happen at quite widely separate times, such, for example, as the normal switching operations in an electrical system, and which furthermore is adapted to record with sufficient accuracy as to time, a very rapid sequence of events, such as a succession of operations by automatic switches brought about by abnormal or accidental circumstances, or which will at least give a definite indication as to which event happened before all the others of the sequence.

We are, nevertheless, generally accustomed to curve drawing instruments in which the time record depends upon the constant progression of a tape, or its equivalent in the form of a rotating paper disk. But in order that the record may not be of practically immeasureable size and commercially out of the question, sacrifice of close accuracy in the time record has to be made by running the tape at a very slow speed. Thus a rapid succession of recorded events are merged indistinguishably together as if but one event had happened, and naturally there is no way of finding out which occurred first.

In the multi-recorder a radical departure from the old way of continuously recording time by constant motion of a tape and superposing thereon the happening of other events, when they happen, has been made, and in its place has been substituted the method of simultaneously printing upon the tape when at rest, the occurrence of a particular event and the time at which it takes place, followed by a slight progression of the tape to receive the record of the succeeding event and time it occurs, and so on.

This is all the record that is needed, when vital events to be noted are not of a continuous or flux character, but take place at definite and recurring instances of time, as, for example in switching operations, for recording which the instrument before us was primarily designed. The record is kept without the use of an inordinate length of tape and is in fact in a very condensed and handy form; nevertheless, accuracy in respect to time is insured to a very close degree. This is the fundamental merit of the apparatus, which has in this instance been reliably put in practical form by skillful attention to mechanical and electrical details.

The applications of the multi-recorder that are apparent are many, and numerous other uses for it will doubtless be found from time to time.

In the paper describing the device, published in the A. I. E. E.

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TRANSACTIONS, Vol. XXXI, 1912, abundant evidence is given of its value for recording switching operations in an electrical system. The record made under normal conditions is a watch over the proper performance of duty by the switchboard attendant, while under accidental and abnormal circumstances the instrument not only stands guard over the attendant to record his correct moves, or his blunders, but may be adapted to pick up and record the shortcomings of the system in respect to the matters that are outside his jurisdiction, or his ability to control.

Its action is so rapid that the sequence of operation of oil switches can be noted. Time-element relays can be checked to the nearest second. Duration of accidental short-circuits and surges can be recorded. It notes whether a feeder is alive, and if so, the time when, and initially from which end, it was energized. It may keep watch over the care of aluminum lightning arresters in respect to charging them properly and at correct intervals, and that they are not abused by charging them for too long a time. The connections of the multi-recorder can be used to make the load dispatcher's dummy switchboard in a power station automatic. More rapid switching can be carried on, as the exact conditions are always before him. Signals and responses from one part of the station to another can be recorded also starting, synchronizing and stopping generators, operation of ventilating motors, and various auxiliary apparatus. Determination of the value of the overhead ground wire of a transmission line by recording the lightning strokes (ordinarily recorded by puncturing paper) is feasible, in which application the instrument would take the place of a large corps of observers located along the line, and with elimination of the confusing uncertainties of many observations tempered by the personal equation of different individuals.

The probable utility of the multi-recorder in automatically noting the time and duration of application of successive steps in manufacturing processes suggests itself; it might be a process for making insulating material, requiring exact intervals of application of current potential and heat, or processes in a chemical works, or in refineries, etc. It might be applied in boiler rooms of large power stations to check the testing of gages the opening and closing of valves, dampers, firing operations, etc.

The operations going on in railway switch towers at important crossings and at large yards and terminals are easily within the ability of the instrument to record; likewise record may be made at headquarters of the calls from police telephone and fire alarm boxes.

Tally can be kept on the operation of some machine tools, for instance, punch presses, to insure that the normal output is forthcoming.

The time when employees come on and go off duty can be centrally recorded.

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We have before us the 24-hour power log of a cement manufacturing company, in the form of a large sheet ruled off vertically for time, and horizontally for apparatus, and for various other data, the record of which is to be noted each hour. The record for "apparatus in operation," includes engine driven generators, exciters, air compressors, condensers, pumps, stoker engines, boilers, and fifty-one motors; there are also places for record of load curve, watt meter readings, general data, miscellaneous readings, coal data, and crews on duty.

This log is filled in daily by hand. The record for all the apparatus noted above could be made by a multi-recorder, and also that for the crews on duty. The application would in this instance be easy, and not necessarily call for an automatic electric contact device on the apparatus to cause a record. The duty of the man on the job would simply be to press one electric button when an apparatus was started, and press another when it stopped. This I believe would insure proper attention to duty in most cases. The man would know that his record was made beyond his ability to alter it, when he pressed the button, and he would be likely to see to it that the record was made at the right time. If, however, circumstances should make it important to record the operation of apparatus beyond any doubt, a suitable electric switch device could be applied thereto; this would absolutely prevent tampering with the time recorded. The log now used presents every opportunity for tampering, to the extent that the operative learns from experience what can be done without detection; it also offers a chance for errors resulting from not making a record at the proper time, but neglecting so to do and trusting to memory to fill it in at a later time. The face of this log is an additional suggestion of possible fields for the commercial application of the multi-recorder.

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(*Subject to final revision for the Transactions.*)

# A COMPARISON OF THE TELEGRAPH WITH THE TELEPHONE AS A MEANS OF COMMUNICATION IN STEAM RAILROAD OPERATION

BY M. H. CLAPP

ABSTRACT OF PAPER

Brief historical descriptions of the use of the telegraph and the telephone on railroads are given, the first train having been handled by telegraph in 1851 and the first handling of trains by telephone on long stretches of main line track having started as late as 1907.

In comparison with the telegraph, the telephone circuits cost more to install and operate, but effect a saving in the operation of the railroad, both directly and indirectly, as it is possible to move trains over the road more rapidly.

The advantages and disadvantages in comparing the telegraph with the telephone are summarized as follows:

*In Favor of the Telephone.* Universality, saving of time, rapidity of transmission, psychological effects, promptness in raising offices, no necessity of specially trained operators, saving in expense of railroad operation, and best operation of circuit in heavy weather.

*In Favor of the Telegraph.* Flexibility in handling circuits, simplicity in installing, maintaining and operating, circuit best adapted for long distances, effects of distance in transmission, saving in cost of installation and maintenance, and the standard of maintenance.

In considering what are termed the four methods of communication, namely: by personal interview, by letter, by telephone or telegraph message, and by telephone conversation, attention is called to the fact that the use of the last-mentioned method by the railroads in this country has not been carried as far as it should.

IN MAKING a comparison between the telegraph and the telephone in their application to railroad operation, it is the purpose to state first the principal physical characteristics of each; secondly, the respective costs of providing and maintaining them, and, finally, the relative advantages and disadvantages of these two means of communication. A brief resume of the early development will possibly serve to make clearer the situation which so long delayed the advent of the telephone for handling trains.

## EARLY DEVELOPMENT

From the beginning of the operation of railroads in the United States in the early 30's, until the early 50's, a period



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of twenty years, there was no system provided for rapid communication from one station to another. Trains were run on what was called the "time-interval system;" briefly, a ruling train had the right of one hour against all opposing trains of the same class. This practise continued for nearly ten years after Prof. Morse had sent his historical message from Washington to Baltimore. At about that time the Erie Railroad Co. constructed a telegraph line, which was first used, apparently, for handling local messages along the road. Finally, in 1851, a train was successfully handled by a telegraph order for a distance of 14 miles (22.5 km.) From this small beginning the handling of trains and messages by telegraph increased very rapidly, until, about ten years later, the telegraph was quite common on the railroads of the country. Contracts were early made between the railroads and the commercial telegraph companies whereby the same pole lines were used by both parties to support their wires along railroad rights-of-way. In the end, the telegraph became an established and invaluable adjunct in railroad operation, as will be described in more detail.

Although the Morse register was early done away with, and messages received entirely by sound, there was some opposition to this on account of the loss of the permanent record, especially when dispatching trains. This matter of not having a record was one of the principal reasons that the telephone was not sooner used for the dispatching of trains; but when this objection to the telephone is analyzed, we find that there is really no difference between the receiving of a message by sound on the telegraph as compared with receiving a message on the telephone, as no record is made in either case by the electrical or mechanical equipment proper. Apparently some of the persons who objected to the use of the telephone on account of its alleged lack of record, had in mind, when they considered the telegraph, the old Morse registers that were first used on the early telegraph circuits.

The railroads early began to use the telephone on different parts of their systems. As the commercial development of the telephone was very slow in this country up to 1890, it would apparently follow that there was not very much use of the telephone on the railroads during the same period. However, the records show that different railroads in the early eighties began to put in telephones for various purposes; not

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so much, however, to replace the telegraph, as to replace messenger service and to serve as an auxiliary to the telegraph. The replacement of the telegraph by the telephone, to any extent, really began only six or seven years ago. It is only during this short period of time that extensive installations of telephone dispatching and message circuits have taken place, although beginning about fifteen years ago there were numerous telephone circuits erected between terminals and principal offices on some of the railroads. These long-haul talking circuits did not primarily replace the telegraph, but in most cases merely provided additional means for communication.

While trains were handled for short distances, principally in and about terminals, beginning back in the early nineties, it was not until the latter part of 1907 that any real attempt was made to handle trains on long stretches of main-line track by telephone. The Chicago, Burlington and Quincy road was one of the first to use telephone train-dispatching circuits on their main lines, and by the latter part of 1908 this company had a considerable mileage of its lines dispatched by telephone. The principal railroads in the East and the middle West at once began to install telephone circuits, so that at present there are some 70,000 miles (112,654 km.) of railroad in the United States dispatched by telephone. The use of the selective-ringing telephone circuit for the dispatching of trains was soon followed by the use of the same kind of circuit for the handling of messages. The growth of the telephone message circuit has, however, been very much slower than that of the dispatching circuit. The primary reason for this is the fact that the telephone message circuit does not meet the conditions on the average railroad to the same advantage as the dispatching circuit, there being more complications to meet than in the case of the dispatching circuit. In general, the message circuit requires a considerable amount of traffic to justify its use. However, it will only be a question of time when all telephone dispatching circuits are paralleled by telephone message circuits.

## A Typical Railroad Telegraph System

The outside and inside plants used by different railroads necessarily vary to a large degree on account of the different sizes, resources, locations and conditions of the railroads served. A description will be given, therefore, of the system on one of the large transcontinental railroads with which the writer is

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most familiar, with particular reference to the conditions about seven years ago, when the present extended use of the telephone for dispatching trains and handling messages had its beginning. It will not be necessary to describe in detail the pole lines used to carry the wires, either telegraph or telephone. It will be sufficient to say that these lines in the United States are in a great majority of cases constructed in accordance with the specifications of the Western Union Telegraph Co., which is substantial construction. These pole lines have at least thirty-five poles to the mile, where the number of wires to provide for is considerable, and in some cases 40, 50, 60 and even 70 and 80 poles per mile are used.

At first iron was universally used for telegraph wires, the size most used being No. 8 B.W.G., thoroughly galvanized. This practise, in general, was not changed as far as the railroads were concerned, except that a considerable amount of copper was put up for long-haul circuits. Of course, copper wire is used quite extensively near large centers or along the seacoast, or wherever corrosion would be troublesome. When copper wire is provided, No. 9 A.W.G. is generally used.

The average cost per mile (1.6 km.) for furnishing and erecting a No. 8 B.W.G. iron wire, including insulators, tie wires and pins, is about $25.00. This wire makes a very good telegraph circuit up to 400 miles without any intermediate offices. At this distance the wire can be worked either singled, duplexed or quadruplexed. With intermediate (way) offices on the line the above-mentioned distance would be cut down to about 200 miles (321.8 km.) The matter of line insulation has a very important bearing on the distance that an iron wire or, in fact, any telegraph wire can be successfully operated. The distances given above assume a high grade of insulation. This mileage for the operation of iron wires, however, is ample for almost any division of a railroad, so that iron wire is very generally used in railroad local (way) circuits, copper wire being used between terminals and the principal points along the line. On the Northern Pacific system, when telephone circuits began to be extensively installed, about seven or eight years ago, there were the following mileages of copper and iron wires in use:

Copper, 4,000 miles (6437 km.)
Iron, 11,500 miles (18,507 km.)

There were practically two through copper wires from St. Paul to Tacoma, a distance of a little less than 2000 miles (3218 km.);

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all the rest of the circuits on and between the different divisions were iron. At that time this wire plant was considered a very good one for the purpose for which it was intended.

The cost per mile for providing and erecting No. 9 B. & S. gage copper wire including insulators, pins and tie wires, varies greatly with the price of copper, but assuming fifteen-cent copper, it would be, on the average, about $38.00.

The equipment of a telegraph office is comparatively simple and needs no description. The following costs will be of interest in comparison with the cost of telephone equipment.

A way station can be cut-in on a telegraph wire, including the battery (gravity) in the office, at a total average cost of ..... $12.00

A switchboard (peg type) large enough to take care of ten wires, in and out, can be provided and installed at a cost of..... $42.00

The cost of providing and installing a twenty-five-line Western Union switchboard, with twenty wires cut in and out, and eight sets of telegraph instruments with necessary tables and battery, is about.... $140.00

Nineteen-conductor cable (No. 14 A.W.G.) suitable for connecting the wires from the line into the offices, can be provided and installed at an average cost of 30 cents per foot.

The average cost of providing and installing a quadruplex set would be about..... $200.00

The average cost of providing and installing a single-line repeater set would be about..... $50.00

At terminals, of course, more apparatus is necessary than at the way-stations along the line. However, a cost of $400.00 would provide and install the equipment in almost any terminal or relay office along the line, except the very largest. While the above-mentioned figures are approximate, and are averages for conditions on the transcontinental line with which the writer is most familiar, they are believed to be reasonable and to give some idea of the cost of providing telegraph circuits along a railroad.

## Railroad Telegraph Traffic

On a railroad on which the telegraph is the only means for transmitting intelligence quickly from point to point on the system, except for short distances in and around terminals where the telephone is used extensively, telegraph communication is used by all departments and by a large percentage of the employes on all occasions and on all subjects. In fact, it is no exaggeration to say in general, that the sending of telegraph messages is made so easy that a great many more messages and words are sent than necessary. The telegraph office is usually located close to the Superintendent's office at division points, and at General

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Headquarters is made as accessible to all departments as possible. In headquarters buildings, where a considerable amount of space and a number of floors are used, pneumatic tube systems are provided in order to carry the messages back and forth between the different offices and the telegraph office.

A considerable amount of railroad business is from its very nature urgent and requires as quick action as possible; for example, reports on the progress of trains over the division, the meeting of the various emergencies that arise, messages about shipments of different kinds, reports of the location of equipment along the road, and similar business.

Each section of railroad has, between terminals, at least one message wire and one dispatcher's wire, unless it is a very unimportant section such as a branch line, where one wire, in a great many cases, serves the purpose for handling both the messages and the dispatching. The length of railroad that can be handled by one telegraph message or dispatching wire depends upon the amount of traffic handled, the size of the towns along the line, kind of country through which the railroad is built, etc. On a busy single-track railroad, 100 miles (160.9 km.) would be a fair limit for telegraph dispatching of trains by the use of one circuit. The facilities necessary for handling the messages would, in a great many cases, be the same as those required for the dispatching, although there would be a great deal more variation in handling the messages than the dispatching. On an important section of railroad there is usually one message circuit that cuts into all offices along the line (way or local circuit) between the two terminals, with other circuits cutting into the more important points.

In order to handle the message service to and from the general headquarters a system of through circuits is provided between the different division points and the general offices. If the length of the railroad system requires it, relay and repeater stations are established. For example, on the Northern Pacific system there are four relay offices between St. Paul, Minn., and Tacoma, Wash. In these offices are located, with a few exceptions, the multiplex telegraph equipments (duplex and quadruplex); there the business is relayed to different offices and terminals to which direct wires are not provided. The wire testing is also handled at these points. On most railroads in the West the operators in the relay offices are on the pay-roll of the Superintendent of Telegraph and are handled directly by him. This

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arrangement tends to give uniformity to the telegraph service on the system.

In order to give an idea of the extent of the telegraph system on the Northern Pacific, the following list is submitted giving the assignment, the character of circuit and the mileage to the destination of the principal telegraph wires working at the present time out of the St. Paul general office:

| Circuit Assignment | Character of Circuit | Distance in Miles |
|---|---|---|
| St. Paul-Tacoma, Wash. | Quadruplex | 1900 |
| St. Paul-Missoula, Mont. | " | 1250 |
| St. Paul-Spokane and Pasco, Wash. | " | 1650 |
| St. Paul-Helena, Mont. | " | 1130 |
| St. Paul-Billings and Livingston, Mont. | " | 1008 |
| St. Paul-Dickinson, N.D., and Glendive, Mont. | " | 667 |
| St. Paul-Fargo and Mandan, N. D., local, 35 offices. | Quadruplex to Fargo Single to Mandan | 450 |
| St. Paul-Fargo, N. D., and Dilworth, Minn. | Quadruplex | 252 |
| St. Paul-Duluth, Minn. | Duplex | 152 |
| St. Paul-Winnipeg, Man., Local, 32 offices. | Single | 483 |
| St. Paul-Fargo, N. D., Local, 41 offices. | Single | 252 |
| St. Paul Division, Local, 30 offices. | Single | 170 |
| St. Paul-Duluth, Minn., Local, 40 offices. | Single | 152 |

This list includes only the principal circuits and does not include certain locals operating out of St. Paul to points in the immediate vicinity of the Twin Cities.

While there is no very accurate record of all the messages handled between all points on the system, the total is estimated at about 5,000,000 per year, not including any messages at present handled by telephone. This would appear to be a large number, even when it is considered that the Northern Pacific is operating over 6000 miles (9656 km.) of mainline track, and it shows, apparently, the free use that is made by this railroad of the telegraph message facilities. According to the writer's observations, the conditions in this respect on other railroads are not materially different.

The cost per message for handling communication by telegraph will probably average more on a railroad than the message cost of the commercial companies, because the messages are handled on the railroad in smaller offices, and on circuits on which the number of offices is larger. The labor cost per message in Northern Pacific relay offices is a trifle over two cents; in offices along the line it would be hard to say what is the actual cost per message, on account of the multifarious duties of the operators at most of these points.

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### Principal Advantages of the Telegraph

The principal advantages of the telegraph are its simplicity and its small cost, both as regards installation and in maintenance; this statement being made, of course, in comparison with the telephone. There are no very complicated circuits in connection with the telegraph, especially at the great majority of the offices along the line. The ordinary lineman has no difficulty in learning how to install and maintain sets of telegraph instruments, and with a little experience, he is able to install duplex and quadruplex apparatus, and Western Union peg switchboards. In general, no particular care is necessary in running telegraph circuits, with respect to one another, in order to avoid induction either in the offices or on the line. In making the last statement, however, the author fully appreciates that telegraph circuits have been seriously interfered with by induction in certain cases; the conditions in mind are those which exist, as a rule, on the great majority of railroads where the telegraph is used. Also, a telegraph circuit will operate under defective maintenance conditions, such as loose connections, unsoldered joints, defective office and cable-box wiring, high resistances in series with circuit, etc., where a telephone circuit would absolutely fail. In other words, the telegraph circuit usually has a considerable amount of margin in operation and will stand a large amount of neglect and abuse. The cost, as already indicated, is small for both line wires and office equipment, and while copper wire is used to some extent, iron wire serves the purpose in a great many cases where it would not be possible to use it in connection with the telephone. The telegraph, also, has the advantage of being a very accurate means of communication. A telegraph sounder makes very clear and distinct signals, and to an expert operator, there is no question as to what has been transmitted; and, if the wire is working at all, the distance is not much of a factor, because the sounder is in a local circuit.

### Disadvantages of the Telegraph

The great disadvantage of the telegraph is its lack of universality. It requires a specialist in order to operate it; that is, an operator who has spent a considerable amount of time, years in some cases, in order to qualify for the work. When carrying on a telegraphic correspondence, one is always working through some one else, never directly. This condition is satisfactory

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in handling some kinds of business, but not for all kinds. The train conductor out on the line can, in the case of an accident, send messages by telegraph to his superior if there is a telegraph office near at hand in which operators are on duty, and accomplish certain results; however, if he can talk directly with his superintendent, a great deal more can be accomplished. The same is true of the section foreman out on the line, the superintendent in his office, and other employes on the division.

There is a decided lack of ability to secure information of the thousand and one emergencies that arise on a railroad, by telegraph, as quickly as desirable. This is due, first, to the fact that comparatively few employes on the system can use the telegraph directly, and second, to the fact that the telegraph is slower as a means of transmitting intelligence than its great competitor, the telephone. It takes longer to transmit a train order by telegraph than by telephone. This disadvantage of the telegraph is especially noticeable when one attempts to discuss any subject over the wire by telegraph, even between expert operators; and where it is obligatory to write out the necessary questions and answers in the form of messages to be sent and received by operators, the superiority of the telephone is even more evident.

The telegraph is at its best in handling messages that are comparatively brief, making definite statements or reports or answering definite questions. As soon as one attempts to ask several questions on different phases or points of a subject, in other words, attempts to discuss it, the telegraph becomes a comparatively slow means of communication.

Trouble is also experienced from delay in getting the offices along the line to answer their calls. In case several wires are looped into an office, and the operator is busy, he may not hear the call when made, or perhaps will pretend that he does not, and it is impossible to prove definitely whether or not the call came in properly. Some attempts have been made to meet this difficulty by providing a telegraph selector at each station that would respond to a certain combination of signals and ring a bell for the particular station desired. However, this device has not been used to any extent by the railroads.

There is, also, the trouble experienced in obtaining operators, which in recent years has become a serious problem, especially when times are prosperous. A railroad which depends at present entirely upon the telegraph has considerable difficulty in se-

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curing operators of any kind, without much regard for their ability. There has been a great falling off not only in the supply, but in the grade of men who enter this field. Twenty or thirty years ago, the conditions were strikingly different, for the reason, perhaps, that there were not then the many opportunities for men to enter electrical pursuits that there are today. Then there is the influence of the labor organization. Practically all railroads have a strong labor organization of telegraphers with which to contend. In making promotions, the labor union appears always to desire to have seniority in the service made the primary consideration, and ability or fitness for a position the secondary consideration. In general, this seniority idea tends to drive the best men out of the service and prevents the ablest men from learning to telegraph.

### The Railroad Telephone Plant

The outside plant necessary in connection with the telephone is substantially the same as that required for the telegraph, except that in practically all cases copper wires are used. Two wires, however, are necessary in order to provide a metallic circuit, and they must be arranged side-by-side on the crossarm and transposed at frequent intervals in order to avoid induction and cross-talk from other circuits. All cables used in looping telephone circuits into offices must have their conductors arranged in twisted pairs, in order to avoid cross-talk.

The great difference between the telegraph and the telephone plants is in connection with the inside plant. Instead of the comparatively simple apparatus, already described, the telephone equipment is more or less complicated. There is first the private branch exchange, which has become so important a part of railroad operation in so many places. These exchanges are, in a great many cases, rented from the telephone companies at the usual rates. However, there are numerous exchanges privately owned and operated, the latest type to be used being the automatic switchboard. Arrangements are made to bring into these branch exchanges the telephone lines of the railroad between the different division points and terminals, to facilitate ready intercommunication. Also, in some cases, arrangements are made so that a railroad official can talk from his office over the lines of the railroad company to any subscriber's station in the public exchange system in a distant city or town.

The cost of telephone circuits for use between the exchanges along the line depends, of course, on the kind and the size of

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line-wire used. The cost per mile of a No. 9 A. W. G. copper circuit in place, on the basis of fifteen-cent copper, is about $75.00. The cost per mile of a No. 6 A. W. G. copper circuit on the same basis, would be about $150. The latter circuit would give, under ordinary conditions, satisfactory telephone transmission up to 1000 miles, while the former would be satisfactory up to about 500 miles (804.6 km.).

The telephone dispatching and message circuits are the most interesting and peculiar to the railroad service. The provision of a means of selectively signaling the different stations along the line was a problem that took some time to solve satisfactorily. These selectors have different designs and principles of operation. In general, the selection is made by a step-by-step mechanism which responds to a certain number of pulsations or combinations of pulsations sent over the line, making it possible to arrange a large number of selective combinations, and thus signal any given station at will, without disturbing the others. Selectors are now made that are very efficient in operation, and will call selectively as many as 125 stations on the same line. At the stations along the line a special form of telephone set is installed for the use of the operators. These sets have a certain combination of apparatus and wiring that provides a so-called "booster" effect in transmission. This is secured by a switch which is so connected in the circuit that when the operator is talking, the receiver is short-circuited, and when the operator is listening, the receiver is connected directly to the line and the transmitter disconnected. Head telephones are provided so that the operator may have free use of his hands. In the dispatcher's office, special telephone sets are used which are wired like the sets at the way stations, except that breast-plate transmitters are usually provided so that the dispatchers can move about sufficiently in making entries on the train sheets, which are usually of considerable length and width. Some of the railroads have experimented with, and are using with some success, loud-speaking transmitters and receivers for the dispatchers. This apparatus, however, has not been developed to the point where it can be used successfully in all cases. Loud-speaking apparatus is greatly to be desired, as the dispatchers complain quite generally of the hardship of wearing continuously the head telephone and the breast-plate transmitter.

The batteries used at the way stations are in most cases com-

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posed of dry cells; they are also used in the majority of cases for the line-battery in the dispatcher's office. These cells are, on the whole, the most economical, as the line current necessary to operate a selector is rarely over 10 milliamperes and in some cases is as low as 1.5 milliamperes. However, small generators are used in some cases to furnish the necessary ringing current; storage cells, also, are used, and both are economical where the circuits are long and there are numerous busy stations on them. In a few cases secondary battery is used at the way stations, but it is not general practise, primary cells being in the great majority of cases the most economical. Wet primary cells are often used for providing the current for the dispatcher's transmitter.

The cost of providing a selector circuit ready for operation under average conditions is as follows:

Cost per station of providing and installing the selector and telephone equipment, protectors and wiring, both outside and inside of the offices, $80.00.

Cost of providing and installing the necessary telephone and selective apparatus, including the battery, in the office of the dispatcher, $250.00. Assuming that a telegraph pole line is already available, the cost of a suitable telephone circuit has already been placed at $75.00 per mile, so that the cost of providing and installing a selective telephone circuit along 100 miles (160.9 km.) of railroad, where there are thirty offices to serve, would be a little over $10,000.

A telephone circuit as described above can be used either as a dispatching circuit or as a message circuit. In arranging for the handling of messages by the telephone, the operator at the terminal office usually remains on the line continuously, thus requiring signaling in one direction only. Often separate rooms are provided for the telephone operators; but in some cases they are placed on opposite sides of the same tables which the telegraph operators use, with good results. The number of messages that can be handled on a telephone message circuit will average twice the number that can be handled by telegraph between the same offices, especially if a typewriter is used in receiving.

Two very useful and time-saving auxilaries which are available with a telephone system are installations of telephones in booths or boxes along the railroad right-of-way at so-called " blind sidings " (where no regular operators are employed, and where there may be not even a station building) and portable telephones for the use of the train crews. Telephones of these

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types can be used to great advantage by the trainmen in handling the many emergencies that arise, and are also of material assistance to the dispatcher, in reducing train delays. Order-forms for use of the trainmen are usually provided along with the telephones installed in booths or boxes and, in some cases, special forms of registers are provided in which the order forms are placed so that three copies can be made of all orders transmitted to the trainmen, one copy in each case being given to the engineman, the second copy to the conductor, and the third copy remaining in the machine as a record.

The portable telephone has obvious advantages in the respect that it can be used at any point along the road, by making temporary attachment to the telephone line-wires. Some of the railroads, however, have installed telephones in boxes or booths along the right-of-way every half mile; in such cases portable telephones could hardly be used to advantage. The telephones along the right-of-way are usually connected to the dispatching circuit so that the trainmen can talk directly to the dispatcher. Where telephones are provided every half mile, they are usually connected to a separate line-circuit, and provisions are made at way stations for switching it to the dispatching circuit.

The cost of a booth installed along the right-of-way, with the necessary telephone apparatus, depends on how elaborate an installation is desired; a very substantial and satisfactory installation can be provided for $90.00, but this can be reduced to possibly $30.00. A good portable telephone can be purchased for $12.00.

In addition to the uses already described, there are various miscellaneous ways in which the telephone can be used on a modern railroad. Telephone sets are placed in the observation cars of limited trains and connected to the railroad company's branch exchange, so that passengers can talk to parties in the city from which the train is leaving, up to the time of departure. The telephone is often installed in freight sheds and in freight yards so as to provide a means of ready communication from one point to another. Special types of telephone sets are installed on the desks of officials and so wired that conversations can be carried on with other officials in the same building by ringing a bell as a signal and then simply talking in an ordinary tone of voice into the telephone set, without the use of the ordinary receiver or transmitter. Local telephones are installed in the homes of trainmen for use in calling them for duty, thus saving time and avoiding the expense of employing messengers.

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The method employed in handling train orders by telephone contains some points of interest. All figures or names of stations occurring in the order are spelled out letter by letter, both in the giving of the order and in all repetitions; also, in handling a "31" order,[1] the name of the conductor is spelled out. The dispatcher writes the order in his train-order book at the same time that he telephones it to the operator or operators on the line. Each operator who receives the order repeats it back to the dispatcher, the dispatcher underlining each word or number as repeated. In operating a message circuit, the same general practise of spelling out words and figures is followed as in the case of the dispatching circuit. The cost of maintenance of the telephone is always more than the telegraph, for the reasons that the telephone is more complicated and has more equipment. In the author's opinion, specially trained men should always be employed to maintain the telephone station equipment, although on some railroads the section linemen are required to maintain the telephone equipment; the last plan, however, produces in most cases indifferent results, in the author's opinion. In order to maintain properly four selective telephone circuits, having an average length of 100 miles each, at least one telephone inspector should be provided at a monthly rate of $85.00 with expenses, and there should be additional force if there are many telephones maintained at different "blind sidings" along the line, or special apparatus installed at various terminals, private-branch exchanges, etc. All of this expense is practically in excess of what is necessary to maintain the telegraph to handle the same work, although, as already indicated, the telephone handles a great many transactions that were never attempted by telegraph.

### Comparative Advantages of the Telephone

The advantages of the telephone are many; some direct, some indirect and some psychological. The first and most important in the author's opinion, is that it permits direct dealing between the parties desiring to transact business. The superintendent can talk directly with his subordinate; the chief dispatcher can talk directly with the trainmen out on the line, and any two employes can deal directly with one another, if the proper telephone facilities have been provided. This is what might be termed

1. A form "31" order requires the signature of engineman and conductor, whereas a form "19" order does not: see "Standard Code", of the American Railway Association.

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the universality of the telephone as compared with the telegraph; every one from the president to the section foremen can use the telephone directly. The telephone, compared with the telegraph, is a great time saver on account of its speed of transmission. Train orders can be handled more rapidly by telephone than by telegraph. This is due to the fact that the orders can actually be transmitted faster over the telephone; also, to the fact that the operators along the line can be made to answer the calls on the telephone bells quicker than their calls on the telegraph. The primary reason for this last condition is the use of four-inch vibrating bells for way-station calling signals, which can be heard from some distance. Again, an operator does not know what is taking place on a telephone line until he comes in on the circuit, while, with the telegraph, the operator by listening can read all that is being sent and, in some cases, can judge as to the relative importance of the calls for his office. A call on the telephone always involves an uncertainty as to what is wanted or who is calling; therefore, in order to be on the safe side, the operator will unconsciously drop any work in which he is engaged and answer the telephone bell when it rings. This peculiarity of the telephone constitutes one of its psychological advantages referred to above. Furthermore, the calling bell is wired so in the circuit that the dispatcher hears it ring, thus removing any doubt as to whether the bell actually rang or not. This is a very important point in favor of the telephone, as it removes any chance for an argument between the dispatcher and the operator as to whether the latter was called.

Since the dispatcher remains on the circuit continuously, the operators along the line can communicate with him without calling, by simply coming in on the circuit and stating whatever information they may have to communicate. On this account it naturally follows that more detailed information is obtained as to train movement, and that the dispatchers can keep in closer touch with their work. In using the telegraph a train dispatcher is not able to transmit his thoughts by one-tenth the speed he could express himself by word of mouth. While a dispatcher cannot send a train order ten times as fast by telephone as by telegraph, he can carry on conversations with operators and trainmen along the line at this rate, which is a great advantage to all concerned. Also with the telephone, the necessity is removed of operating trains through the medium of a large number of men of varying ability. Then there is

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the human side of the telephone system; the men along the line get very much better acquainted over the telephone than over the telegraph, and coöperate to greater advantage. This condition was largely unknown when using the telegraph, and is not the least of the advantages in the use of the telephone.

By the use of the telephone, the field from which dispatchers and operators can be recruited is naturally broadened. It is no longer necessary on a railroad where the telephone has been installed with a sufficient number of circuits to keep the service intact, to depend on telegraph operators, in other words, specialists. There is, for example, one division on the Pennsylvania Railroad where out of about 400 operators' positions along the line, it is necessary to fill only eight of them with telegraph operators. This is a very important point for consideration in these days when, as already stated, the supply of telegraph operators is not equal to the demand. Also, it is possible to use as a dispatcher an employe other than one who has obtained his experience in the telegraph or telephone service, as, for example, a freight or passenger conductor.

While a telephone circuit is, in most cases, more susceptible to outside influences than the telegraph, experience shows that in heavy weather, heavy fog, mist, rain or snow, less trouble is experienced with the telephone than with the telegraph; and the telephone is affected only to a small degree by earth currents or by the aurora borealis.

Finally, we have for consideration the saving in the operation of the railroad by the use of the telephone. Unfortunately, it is hard to show in all cases a saving, because many of the best-known economies are more or less intangible. One is generally sure that he is saving time by using the telephone, and it seems at least a fair assumption that there is a corresponding money saving. The psychological effects can be capitalized to some extent, but it is generally difficult to do it. In the way of direct saving, the ability of the dispatcher to get his trains over the division quickly, thereby economizing in operating expenses, is the most evident, and easiest to understand. This is especially noticeable in the amount of overtime that can be saved in the pay rolls of the trainmen and the enginemen. As it is conservatively estimated that the trains can be handled over a division from 10 per cent to 20 per cent more rapidly by telephone than by telegraph, an approximate estimate of the overtime saved can be prepared by considering

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a certain operating division before and after the telegraph is replaced by the telephone. For example, on a certain division where the Northern Pacific is now installing the telephone, both for handling trains and for handling the messages along the line, it has been estimated that a saving of about $200.00 per month will be made in overtime paid to trainmen and enginemen, to say nothing of the other indirect savings of which mention has already been made. In some cases, a direct saving can be made by using a smaller number of dispatchers when handling a given section of railroad by telephone, as compared with the telegraph. For example, there is a division on the Northern Pacific which is made up of four consecutive districts, having an average length of a little over 100 miles each. Part of the year, the four districts can be handled by using two telephone dispatching circuits; but when there is considerable business on the railroad, four dispatching circuits are used. It would be necessary with the telegraph, to handle the four districts by using four circuits at all seasons of the year. As it requires three dispatchers to handle one dispatcher's circuit during the entire twenty-four hours, and as the salary of a trick dispatcher is $155.00 per month, the abandonment of any of these positions even for a part of the year is a very desirable thing from the standpoint of saving in expenses.

Savings are also made possible by the installation of telephones in booths or boxes at or near small and unimportant stations along the line where operators have been employed, thus resulting in the closing of these stations for a portion of the day, at least, and reducing the number of operators. In some cases, less expensive operators are employed when the telephone is installed; this practise is quite common on some of the railroads, and is done both at the stations along the line and in the offices at terminals and headquarters. In the latter case female employes are often used to advantage, as all that is necessary is a reasonable familiarity with the business to be handled and the ability to operate a typewriter.

### Disadvantages of the Telephone

The principal disadvantages of the telephone as compared with the telegraph is its cost of installation and maintenance. However, these increased costs are overcome by the savings that are made possible. Another disadvantage is that the telephone, in the present state of the art, is not adapted, on account of excessive cost, for use on the railroad for any considerable

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distance. While there is a circuit about 1000 miles in length in operation on one railroad in this country, at least, this circuit is used entirely as a talking-circuit and is not used for message work. It requires a good margin of transmission to handle messages over a telephone circuit and, according to the author's experience, a circuit equating to more than 26 miles of standard[2] cable should not be used in railroad service; at least, not in connection with handling trains or messages.

While it is possible to construct a telephone circuit 2000 miles (3218 km.) long, or even longer, that would have the proper transmission efficiency, it will apparently be some time before a railroad can justify such a circuit, from the standpoint of first cost and maintenance expense, and benefits derived. The telegraph will probably continue to handle the messages for the long distances, such as 500, 1000, or 1500 miles (804, 1609 or 2414 km.) for a considerable time to come.

The telephone is not as flexible as the telegraph when making patches in cases of trouble on the regular wires. For example, suppose that the entire pole-line is down at some point between two terminals, it is very easy to re-establish a telegraph circuit over some second route, even though it be very circuitous. If the circuit is too long for direct working, repeaters can be cut into the circuit at intermediate points. For example, it is entirely possible for the Northern Pacific to obtain a circuit from the Western Union Telegraph Co. via Omaha, Denver, Cheyenne, Ogden and Portland, and work directly between its St. Paul and Tacoma offices. But it is impossible to establish an emergency telephone circuit for the distance involved in the above example, or for considerably shorter distances.

The telephone requires a much higher efficiency of maintenance than the telegraph. This is not, strictly speaking, a disadvantage. In fact, the telegraph wires and apparatus should be maintained as well as the telephone system, but in practise this is not done except in very few cases. Also, there are more delicate parts in the telephone apparatus, to get out of order, than in the telegraph. The required efficiency of maintenance is not as easy to establish, on a railroad, as might be thought. The telegraph and telephone plant is necessarily spread out over the entire system, without very much of it in any one place; this makes it difficult to secure adequate super-

2. Standard cable has a resistance of 88 ohms per unit (No. 19 A. W. G. metallic) and a mutual capacity of 0.054 microfarads per mile.

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vision, and it is not easy to impress upon the different employes who have to do with the maintenance of the plant, the importance of keeping the lines and apparatus in proper condition.

### Summary of Relative Advantages of the Telegraph and the Telephone

The following summary presents the respective advantages and disadvantages of the telegraph and the telephone.

The advantages of the telegraph are: (1) Flexibility in handling circuits; (2) simplicity of installation, operation and maintenance; (3) best adapted for long-distance service; (4) least affected by distance, in respect to transmission efficiency; (5) low cost of installation and maintenance; (6) the necessary standard of maintenance is not difficult to secure.

The advantages of the telephone are: (1) Universality; (2) saving of time; (3) rapidity of transmission or dispatch of business; (4) psychological effects; (5) minimum delay in getting offices to answer calls; (6) lack of necessity of trained specialists to operate the service; (7) saving in total expenses of railroad operation; (8) minimum impairment of transmission efficiency in heavy weather.

### Applications of the Telephones

As yet very few railroads are using the telephone as much as they could or should. Because many of the economies with the telephone are more or less intangible, railroad managers are rather cautious in authorizing its wholesale installation. They are usually ready to authorize telephone dispatching circuits, as the savings from them are more easily understood than in other applications. In the author's opinion, the up-to-date railroad of the future will handle its operating divisions entirely by telephone, the telegraph being used only for message work for long distances between the terminals and the general headquarters. On the divisions, the typical way office will have no telegraph instruments, and will depend entirely upon the telephone for handling all messages. At all terminal points and important offices along the line, private-branch exchanges will be installed, which will be connected with each other by means of talking circuits, so that any two employes on the same division or adjacent divisions can communicate with one another easily and quickly. Telephones will be installed in booths or boxes along the right-of-way at frequent intervals, such as every half-mile, and the necessary lines and apparatus provided

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so that trainmen, sectionmen or any one out on the line can obtain ready communication with persons with whom they may have business to transact. Where portable sets can be used to advantage, they will be furnished to such employes as trainmen, sectionmen, linemen, signal maintainers, etc., so that connections can be made directly to the telephone line-wires at any point along the line. Ample telephone service will be provided at all points, especially where private-branch exchanges are installed, so that all employes having any legitimate need to talk to one another can do so without delay, whether in the same city or town, or at points on the same division, or other divisions, within a possible limit of 1000 miles. Also, the railroads will not forget to provide ample service so that the public can reach certain authorized employes by telephone, promptly, when necessary.

The above outline of the applications of the telephone to the needs of a railroad is not entirely prophecy, since there are railroads in this country already using the telephone, on portions of their systems at least, almost as extensively as contemplated in the foregoing description.

There are four general methods of communication, namely: by personal interview, by letter, by telegraph or telephone message, and by telephone conversation. There are certain business transactions that can best be handled by only one of the above methods; there are others that can be handled by two or more of these methods; and in some cases, by any one of the four. Without doubt there is always one of these methods, as a rule, that is best adapted to any particular transaction. While a great deal of traveling is done by railroad men, there is still, in the author's judgment, a lack of personal contact in a great many of the departments between the man in charge and the men in the field; in other words, there is a lack of supervision. There is probably no lack in the number of letters written; and there is no doubt at all that too many telegraph messages are sent. The telephone as a means of communication is not, however, used as it should be on the railroads in this country. As already pointed out, the local use of the telephone has been well developed in a great many places, and the same is true of its use in dispatching trains; but its universal application as a means of communication, and its substitution for and its use as an auxiliary to the telegraph, have only in a very few instances been carried to a logical conclusion.

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*To be presented at the 292d Meeting of the American Institute of Electrical Engineers, New York, March 13, 1914, under the auspices of the Telegraphy and Telephony Committee.*

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# TRAFFIC STUDIES IN AUTOMATIC-SWITCHBOARD TELEPHONE SYSTEMS

BY W. LEE CAMPBELL

ABSTRACT OF PAPER

The paper describes a telephone traffic recording machine by means of which not only the number of calls for a given period, but also the average duration of each call, is mechanically registered on a moving tape. The observations recorded here were taken on an automatic telephone system. The graphical record shows the exact duration of each connection, the number of connections made during a given interval, and the number of simultaneous connections in service at each instant. By means of these records it is possible to study the relative efficiency of small and large trunk groups, the average holding time of calls, and these observations permit the switches and trunks to be so arranged that the calls will be evenly distributed among the trunks in each group.

THE WORD "traffic" as used in telephone practise applies to the volume of calls which a system handles. To measure traffic it is necessary to know not only the number of calls for a given period or interval of time, but also the average duration of each connection or call. A knowledge of traffic, and the laws governing it, is essential to the proper design and operation of either an automatic or a manual system.

## OBSERVATIONS OF TRAFFIC

In well managed manual switchboard central offices it is customary to study traffic conditions by taking peg counts and plug counts. A peg count is a count of all connections made during a definite time interval by each of the operators. A plug count is a count at a definite instant of all plugs in use. In addition to these, stop-watch observations must be made to determine the average length of connection, or "trunk holding time", as it is often called. Where the trunk holding time is known, a good way to take both a peg count and a plug count has been to use a recording ammeter connected into a circuit supplying energy to some or all of the relays; then knowing the average ampere-hours consumed by each connection, it is a



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comparatively simple matter to determine from the ammeter records both the total number of connections made and the maximum number of connections existing at the busiest instant. The latter is an especially important matter because it determines the amount of connecting equipment required to take care of the peak load.

It is very difficult, if not impossible to secure a very accurate peg count or plug count. Operators frequently make mistakes in registering calls during a peg count and observers make mistakes in counting plugs; mistakes are also made in distinguishing between cord circuits actually in use and those which are apparently in service but really idle, because the conversation of the parties using them has been completed.

In automatic central offices, counts corresponding to peg counts are occasionally taken by counting the operating switches as they complete connections. Calls are also counted by the use of a meter on each trunk; these are generally installed by connecting the release magnets of 2nd or 3rd selector switches on each section of the switchboard to a separate busbar, in series with which is a $\frac{1}{2}$-ohm relay which operates each time a switch releases, and closes a circuit through a meter. Counts similar to plug counts have been taken by counting all of the like trunking switches in operated position at given times.

## Traffic-Recording Machine

All of these methods of measuring traffic have their disadvantages and it is believed, therefore, that telephone traffic engineers and telephone engineers in general will be interested in a new recording device and some of the results secured by its use during the past year in making traffic studies in automatic switchboard plants, on a somewhat elaborate scale. The special feature aimed at in this machine was to secure a graphical record which would show the exact duration of each connection, the number of connections made during a given interval and the number of bona-fide simultaneous connections in service at each instant.

The machine as devised consists of a mechanism for passing a strip of paper about 6 in. (15.2 cm.) wide over an inked ribbon and onto a receiving roll at definite rate of speed, with a number of markers (40 in all) arranged side by side over the paper, so that when any marker is pressed against the paper the inked ribbon leaves a corresponding line on the paper. Each marker

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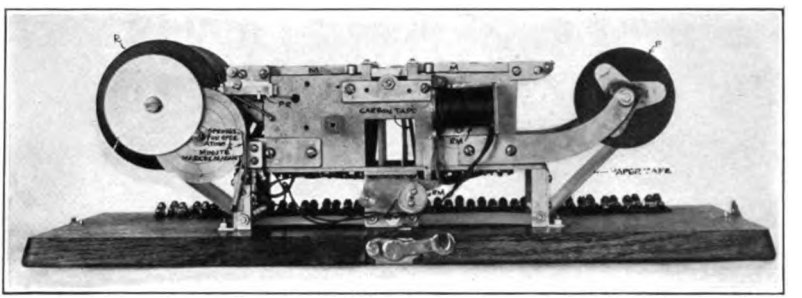
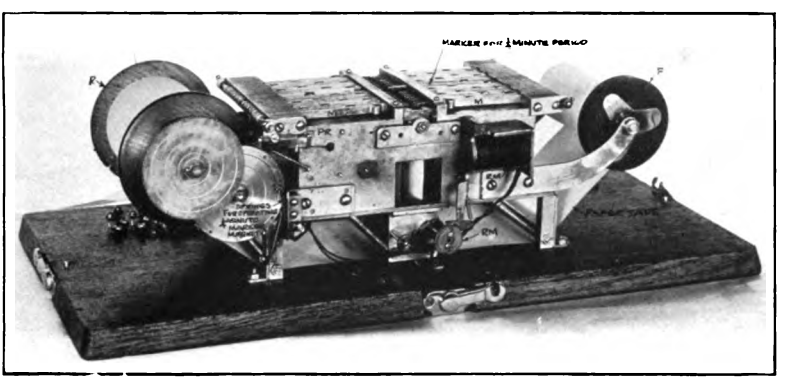


[CAMPBELL]




[CAMPBELL]

FIG. 1

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is provided with an armature and an electromagnet for operating it; the latter is electrically connected to the mechanism associated with one automatic switchboard trunk in such a way that whenever that trunk is occupied by a call, the potential established on the trunk for guarding purposes serves also to cause current to flow through the electromagnet and energize it as long as the connection lasts.

Two views of this machine are shown in Fig. 1. $F$ is the roll feeding paper to the machine; $R$ is the receiving roll; $M$ are the markers; $V$ is a pendulum virbator tuned to run at a fixed speed, so as to make and break at regular intervals the circuit through the electromagnet operating the step-by-step pawl and ratchet movement $P$ $R$, which turns the receiving roll and thus draws the paper through the machine; $R$ $M$ is a device for moving the ribbon at intervals so that the portion immediately under the markers will always be sufficiently inked. A skeleton view of the mechanism with its associated circuits is shown in Fig. 2.

## Sample Observations with Machine

A section of the paper tape taken from the machine and covering a record of calls during a busy half-hour on a set of trunks in the business central office of a city in Michigan is shown in Fig. 3.

One especially interesting feature is the remarkably short period of time which occurred in many instances between the release of a trunk and its seizure for another connection. This is of material aid in promoting trunk efficiency, and is due to the automatic switchboard. As indicated in the figure, the vertical lines mark $\frac{1}{4}$-min. periods. It was found that by means of a chartometer, it was not a difficult matter to sum up the lengths of the lines on each tape, so that the average length of call might be obtained; and it is apparent that a curve may be very readily made from this sheet, which will show the number of simultaneous connections at each instant, as the curves in Fig. 4. In fact, any traffic data desired may be secured from the tape.

The upper curves $A$ and $B$, in Fig. 4, are taken respectively from the upper and lower halves of the same tape, from whose totals the lower curve was constructed.

## Trunk Efficiency

The writer's purpose in presenting these curves is to give a graphical illustration of the relative efficiency of small and large

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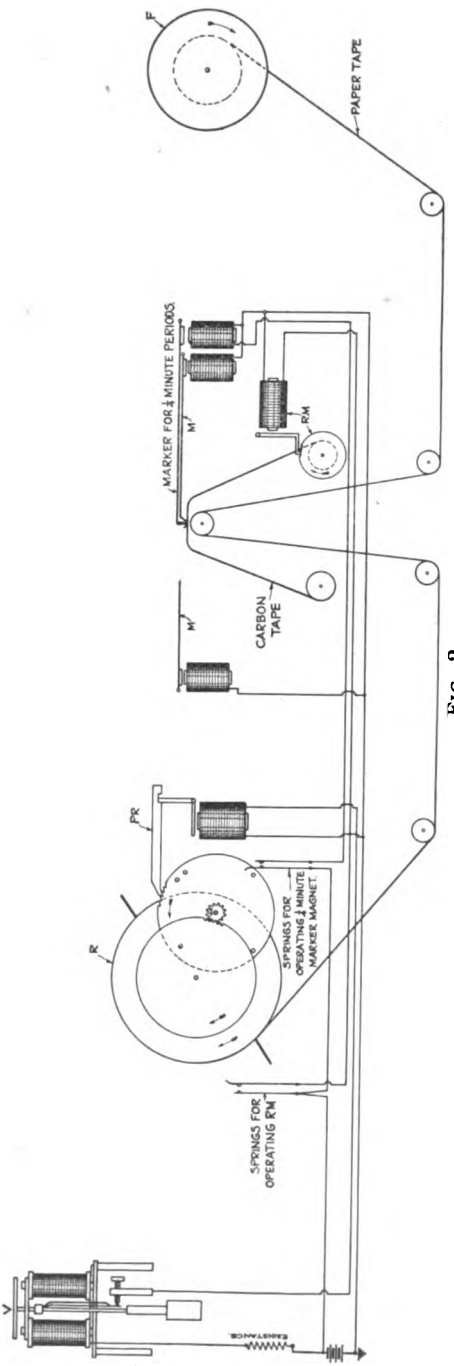
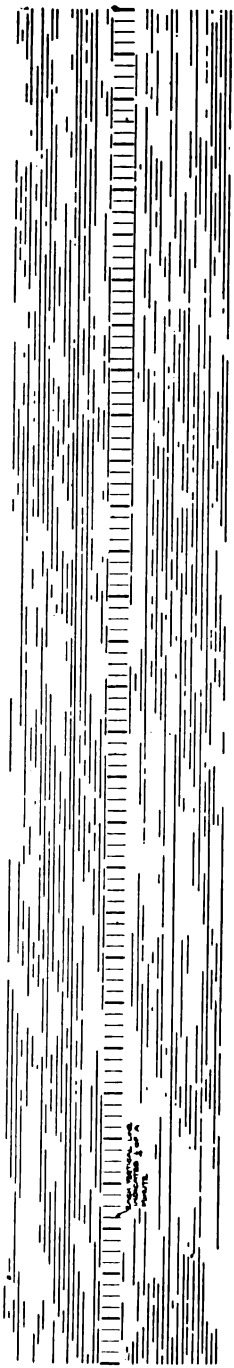



FIG. 2



SECTION FROM TAPE OF TRAFFIC RECORDING MACHINE.

FIG. 3

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trunk groups, by noting the fact that while in the group *A* the maximum number of simultaneous connections is 18 and in group *B* the maximum number is 18, the maximum number in a combination of the two is not 18 plus 18, but 32. This is merely an illustration of the law of increase in efficiency of trunks as the size of the group increases which has been well known to telephone engineers for years; but the author is not aware of any other device which makes it possible to study the working of the law so satisfactorily. The fact that the greater efficiency of large trunk groups is due to a smaller ratio of peak load to average load is very clearly demonstrated by the curves

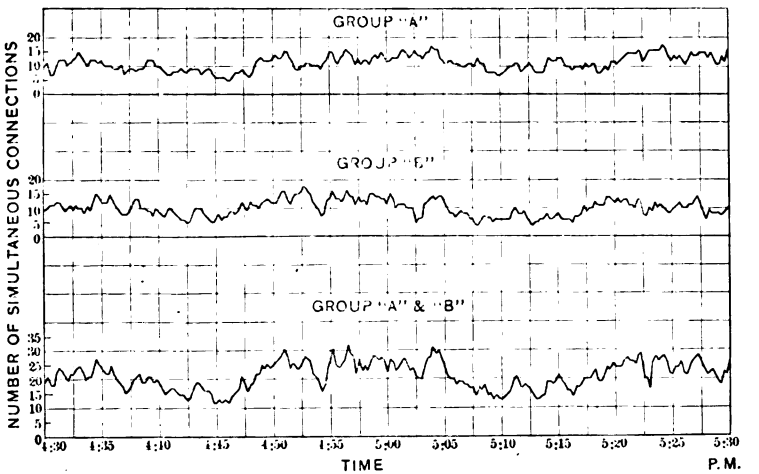


FIG. 4

in Fig. 5, which were constructed from data secured in an office of 7950 lines, by making simultaneous observations during the busy period of each of six working days, on the number of connections in service at given instants in each 100-line section of the entire plant. Note the much greater variation (Fig. 5) in the percentage of connections in the average 100-line group than in the 1000-line section, and the very small variation in the load of the entire plant.

It is customary to define the peak load in terms of the average load or the total busy-hour load. One of the curves, *A* in Fig. 6, shows, for calls of 83 seconds duration, the relation between the total busy-hour load and the peak load, in automatic

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switchboards; or, in other words, the number of trunks needed at the peak instant for busy-hour loads of various sizes. This curve follows the formula:

$$\text{Number of trunks} = T\ C + 3.785\ (1-T)\sqrt[3]{C\ T} \qquad (1)$$

For call lengths of less than 130 sec. this formula may be written in the simplified form:

$$\text{Number of trunks} = T\ C + 3.7\ \sqrt[3]{T\ C} \qquad (2)$$

$T$ is the average holding time in hours, and $C$ is the number of busy-hour calls.

## Average Holding Time

The curve $B$ in Figure 6 is drawn for an average holding time of 83 seconds, because some tens of thousands of obser-

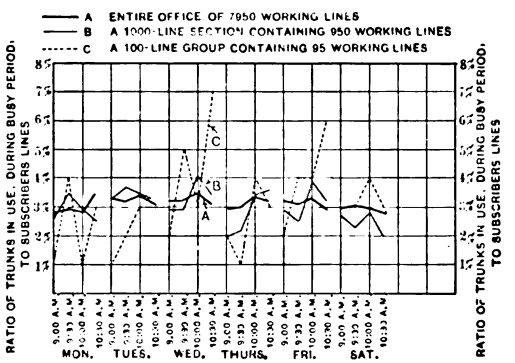
A ENTIRE OFFICE OF 7950 WORKING LINES
B A 1000-LINE SECTION CONTAINING 950 WORKING LINES
C A 100-LINE GROUP CONTAINING 95 WORKING LINES
RATIO OF TRUNKS IN USE DURING BUSY PERIOD TO SUBSCRIBERS LINES
MON.
TUES.
WED.
THURS.
FRI.
SAT.

FIG. 5

vations made in different automatic plants show this to be slightly above the average duration of connection. The 83-sec. standard is divided as follows:

| | | |
|---|---|---|
| Setting up of automatic connection | 6 | sec. |
| Waiting for called party to respond | 9.5 | " |
| Conversation | 66.5 | " |
| Release of connection | 1 | " |
| Total | 83 | sec. |

Call lengths vary greatly in different offices. For example, in one of the cities in which studies were made with the traffic recording machine, it was found that while the average length of calls for the entire system was 81.25 sec., it was 130 sec. on the trunks to an outlying residence office and 100 sec. on trunks to

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manual private-branch exchanges; but observations made on inter-communicating calls in automatic private-branch exchanges have, in a number of instances, shown an average call length as low as 43 sec.

In connection with the studies of average call length, it was found that in approximately 12 per cent of the calls the calling party received the busy signal; and 16 per cent received no response from the called party, either because he was beyond the reach of the telephone, or did not answer the signal before the calling party disconnected.

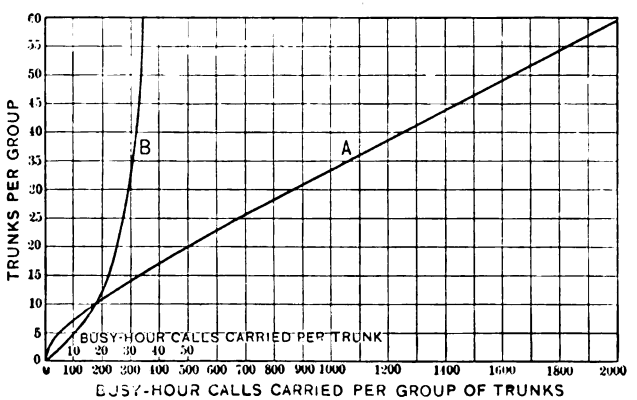


FIG. 6

Curve *A* shows relation between the number of busy-hour calls and circuits in a group. Average holding time 83 sec. Automatic system.
Curve *B* shows the relation between the number of circuits in a group and the number of busy-hour calls carried per circuit.

## TRUNK GROUPING

It is common practise in automatic switchboard systems to arrange the switches and the trunks so that the calls will be evenly distributed among the trunks in each group. This is done to distribute the wear on the trunking switches, to ensure all the switches enough operation to keep them in good working order and to reduce the risk of two parties seizing a trunk at the same instant. Sometimes it is advisable, however, to provide that the trunks in a group will be selected successively: for example, if there are 10 trunks in a group, the trunk-selecting mechanism will test the trunks in order, starting at No.1 for each call, and seize the first trunk that is disengaged.

In Fig. 6A are shown some curves showing results of observations made with the traffic-recording machine on groups of

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trunks successively selected. The shape of these curves gave rise to the suggestion that two groups of 10 trunks each, for example, might be reduced without loss to two individual groups of 7 trunks each and a common group of 3 trunks, which would be a total of 17 trunks instead of 20, by connecting in multiple the 8th, 9th, and 10th trunks of each group after the manner

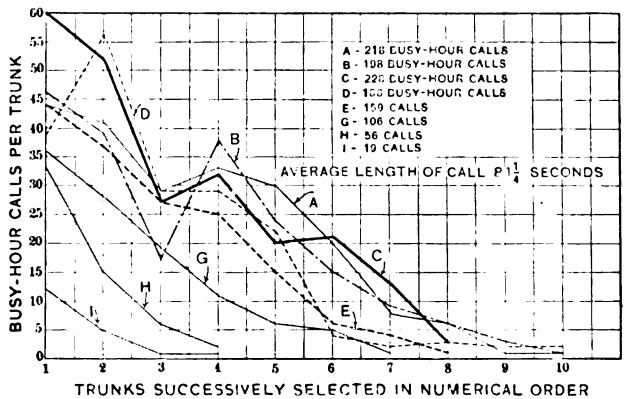
A - 218 BUSY-HOUR CALLS
B - 108 BUSY-HOUR CALLS
C - 228 BUSY-HOUR CALLS
D - 158 BUSY-HOUR CALLS
E - 159 CALLS
G - 106 CALLS
H - 56 CALLS
I - 19 CALLS
AVERAGE LENGTH OF CALL P1¼ SECONDS
BUSY-HOUR CALLS PER TRUNK
TRUNKS SUCCESSIVELY SELECTED IN NUMERICAL ORDER

FIG. 6A

shown in Fig. 7. The effect of this method of connecting the groups together is illustrated in Fig. 8, which shows the load curves of the two groups of trunks overlapped in such a way that the one busy-hour call of the 10th trunk in each group is superimposed on the 9 busy-hour calls of the 7th trunk in the other group, while the 3 busy-hour calls of the 9th trunk in one group are combined with those of the same trunk in the other group.

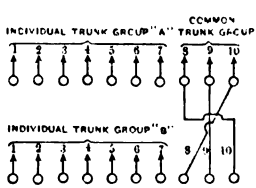


FIG. 7

It is argued by those who suggest this scheme that since, as shown in Fig. 6, a group of subscribers *A* making 175 busy-hour calls would require but 10 trunks and a similar group *B* would require but 10 trunks, while a group of subscribers making 350 busy-hour calls would require but 16 trunks, the arrangement in Fig. 8 satisfies all requirements; because it must be true that the peak loads in the two sets of 10 trunks each would practically never overlap, so that both groups of subscribers would never want the 3 common trunks at the same time, or else the curve in Fig. 6 and the law governing it are fallacious.

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There is one other factor to be considered, however, and that is the possibility of calls overhanging on the 3 common trunks, while some of the subscribers of the group *A*, for example, are not calling, and group *B* parties are endeavoring to secure access to the common trunks. The arrangement in Fig. 7 and Fig. 8 allows an extra trunk to overcome this objection, *i. e.*, allows

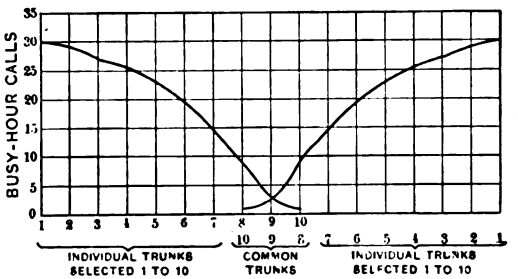


FIG. 8

17 trunks for 350 busy-hour calls, while but 16 would be required if all subscribers had access to every trunk.

Whether this arrangement will be justified by experience and become of practical value, the writer would not venture to say at this time. It seems probable that it could be practised to advantage where two-way trunk service is to be given. As the writer mentioned in a previous paper, there is generally a dif-

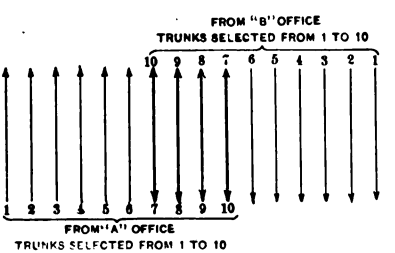


FIG. 9

ference in the times at which the peak loads occur on trunk groups carrying traffic in opposite directions between two offices, consequently the use of two-way trunks would reduce the number of trunks required. While such trunks have not been found feasible between large manual offices, they are nevertheless practical, and some of them are in use in automatic systems.

The obstacle in the way of their more general installation

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is the increased cost of trunking equipment. This obstacle can be largely eliminated by the scheme illustrated in Fig. 9, which shows 16 trunks inter-connecting two offices $A$ and $B$, in such a way that each office has access to six individual one-way trunks and four two-way or common trunks. This plan allows for a peak load in either direction of 175 busy-hour calls, provided the two peaks do not occur at the same time, and the combined group would carry a load of at least 240 calls. It is evident that the number of common trunks might be greater or less than four in a total of 20, and would be determined by the relation between the two-way peak load and the peak of the load in each direction; also that the expensive two-way equipment is confined to the comparatively few two-way trunks.

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*To be presented at the Cleveland Section Meeting of the American Institute of Electrical Engineers, Cleveland, Ohio, March 23, 1914.*

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# SIXTY-CYCLE SYNCHRONOUS CONVERTERS

BY L. P. CRECELIUS

ABSTRACT OF PAPER

The paper describes some 60-cycle, six-phase, 600-volt, synchronous converters used in railway substations in the suburbs of Cleveland. The advantages of the use of 60-cycle apparatus include standardization of frequency, low cost and high efficiency. The converters are of the commutating pole type and a number of special features of their design are described. The improvement of commutation due to commutating poles makes it possible to use fewer poles and higher armature speed, but this has the objection of increasing the noise, which would have been objectionable in neighborhoods where these machines were used. To overcome the noise the armature ends were sealed up and a shield provided behind the front leads, thereby cutting down the ventilation to a considerable extent. The field windings were compounded in order to hold the d-c. voltage constant, and in order to maintain the power factor of the supply circuit at unity the converters were over-excited to produce a leading wattless current sufficient to overcome the reactance drop. In order to overcome the heating effect due to restricted ventilation and over-excitation the value of 3500 amperes per square inch of armature conductor based upon d-c. output at rating was adopted. To permit of a-c. starting the copper dampers are interconnected between the poles to produce a squirrel cage connection all around the field structure. Extracts from the specifications under which these machines were built are appended, as well as extracts from the contract under which the power supplied to the substations is purchased.

ONE year's experience with the successful operation of 15,000 kw. of 60-cycle, six-phase, 600-volt, d-c. synchronous converter substation equipment, establishes a precedent for the use of 60-cycle current for purely railway use upon such a scale. This equipment is installed in four substations located in the suburbs of Cleveland.

The fact that only such apparatus that could be depended upon *without question* could be employed to supply efficiently the d-c. power for the railway, required, in the absence of standard practise in the use of 60-cycle converters for this purpose, a very critical and careful consideration on the part of the purchaser, of the essential details of design.

Extracts from the specifications under which the equipment was manufactured are appended, also extracts from the contract



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under which the power supply to the substations is purchased. These contracts are correlated in that the former determined the design of the apparatus best suited to take full advantage of the power company's 60-cycle service offered for sale at cost under certain conditions. Both contracts therefore contain some unusual provisions, a few of the more important of which will be briefly alluded to in the following pages.

## Synchronous Converters

The introduction of the commutating pole has been extremely beneficial to commutating apparatus, especially in the case of converters. Affording the means of increasing materially the output per pole, it has caused a corresponding reduction of the number of poles per machine, thus providing a marked improvement in the mechanical design of the 60-cycle converter. More latitude in the width of pole face and spacing of brushes has been secured, thereby working towards the mitigation of the disastrous consequences of flash-overs.

The commutating pole, by reason of its rectifying influence upon the armature conductors at the instant of commutation, has also been the means whereby, at the same time, good commutation is secured at the higher speed resulting from the use of fewer poles. This increase in speed, however, has one serious objection from an operating standpoint, viz., noise. In addition to such noises ( current and magnetic) as are inherent in all machines irrespective of speed, and are not especially objectionable, there must be included windage and brush chatter which increase at a tremendous rate with speed. The operation of several machines, such as those under discussion, in one station, without compensating for this, is simply out of the question, as the sounding of alarms and ringing of telltale bells cannot be heard. Besides having a detrimental effect upon the nervous system of the operators, the noise would soon be declared a public nuisance in the neighborhood. By far the most objectionable portion of the noise is due to high-pitched windage tones and these have been practically eliminated by sealing up both ends of the armature and providing a shield behind the front leads. Cutting down on ventilation to this extent requires that careful consideration to be given to the size of the armature conductors.

Another important point affecting the temperature of the armature winding is the rapid temperature rise of the conductors lying close to the collector ring taps, which is out of all propor-

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tion to that of the balance of the winding when operating converters at less than unity power factor. This heating is not uniformly distributed on either side of the tap, but shifts from one side at leading power factor to the other side with lagging power factor.

It is highly desirable in railway work to hold fairly constant d-c. voltage on converters and the simplest way to do this is to compound the field winding. This has several other incidental advantages, one of which is to lock the converters together through an equalizer switch which holds them in parallel on short circuits, which are frequent upon railway systems. The amount of compounding desired varies with the extent and character of load fluctuations, line drop, etc., but whatever the amount it must be offset with reactance in the supply circuit, and in order to prevent its disturbing influence upon the regulation of the system it must be located at the receiving end of the line. In this case it has been given a low value because of the comparatively steady load and low resistance of the circuit.

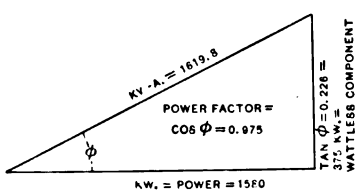


FIG. 1

To maintain the power factor of the supply circuit at unity, as required by the contract [section 9, paragraphs (c) and (d)], calls for over-excitation of the converters to produce a leading wattless current sufficient to overcome the reactance drop. The effect of this is to produce heating in the armature conductors above that caused by the load. When overloading occurs this becomes serious, as may be illustrated as follows:

In Fig. 1 the relations between kilovolt-amperes, and kilowatt and wattless component are represented graphically and given the values at which the converters are operated at rating.

Theoretically the ratio between the heating of the winding of a six-phase converter operated as a converter at unity power factor and running as a generator mechanically driven are,

| | |
|---|---|
| Average value of all coils | 0.27 to 1 |
| Coils tapped to slip rings | 0.418 to 1 |

but when the converters are operated at 0.975 power factor as shown in the diagram the heating ratios become,

| | |
|---|---|
| Average value of all coils | 0.313 to 1 |
| Coils tapped to slip rings | 0.656 to 1 |

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This means that the average coil has become 15 per cent hotter and the tapped coils 57 per cent hotter at the same load. When overloading to 150 per cent rating these values are:

Average coil $1.15 \times (1.5)^2 = 2.59$ times the heating at 100 per cent load and 100 per cent power factor.

Tapped coil $1.57 \times (1.5)^2 = 3.63$ times the heating at 100 per cent load and 100 per cent power factor.

This indicates the wisdom of holding reactance to low values when unity power factor is essential in the supply circuit. It was due to the imposed limitations of power factor and restricted ventilation that a value of 3500 amperes per square inch of armature conductor based upon d-c. output at rating, was placed in the specification.

The provision relating to flux density indicates the purchaser's desire to have considerable generator capacity in the machines to drag through short circuits on the d-c. side. On the railway system in question, short circuits occur in the ratio of 428 d-c. to five a-c. per annum per substation. These are caused by falling trolley wires, cars opening breakers, etc., and comprise a factor to be reckoned with.

## Field Dampers

To permit of a-c. starting with low reactance in the armature and the main field poles fully equipped with pure copper dampers, it is necessary to interconnect or bridge the dampers between poles, to produce a squirrel cage connection all around the field structure. This bridging of gaps between poles causes the commutating pole to become surrounded by the field damper circuit, and seems objectionable because of the possibility of making this field sluggish to load changes. Although this has undoubtedly some slight influence upon the sensitiveness of the commutating pole, it is not noticeable in practise. The fact is that a low-resistance field damper circuit of pure copper grids is far superior to any other arrangement, as several combinations of open and bridged damper circuits of various resistances were tried.

A much-debated question has been the effect of commutating poles upon converters at times of hunting, and it may not be out of place here to record the behavior of these machines when turbine-driven and engine-driven. The power supply is generated by turbine-driven generators and no hunting takes place, but several times for short intervals engine-driven generators

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were paralleled with the turbines and the operation of he converters carefully observed. Instantly a wild hunting is set up, the pulsations of which agree in frequency with the speed of the engines, viz., 100 rev. per min., accompanied by violent sparking at the brushes at very light loads, and flash-over takes place at about full load. Thus at any stage the operation is absolutely unsatisfactory. Upon the same generators may be operated, without much trouble in this respect, other synchronous apparatus including low-voltage converters without commutating poles, although the pulsations from the engines are distinctly noticeable at these machines. It is not at all unlikely that the heavy resulting armature reaction at times of hunting reverses the polarity of the commutating pole, thus becoming the means of exaggerating very much the tendency to flash-over.

In this connection it is interesting to note the agreement between the natural or characteristic period of oscillation of the converters and the pulsations of the supply circuit. This may be determined by Kapp's formula* as follows:

$$N = 24{,}400 \times \sqrt{\frac{P \times p}{Wr^2 \times S \times \theta}}$$

in which

$N$ = natural period in swings per minute
$S$ = revolutions per minute
$P$ = rated output in kw.
$Wr^2$ = weight in pounds of rotating element times (radius of gyration)$^2$ in feet.
$p$ = number of poles.
$\theta$ = the angle in degrees whose sine is full-load a-c. current divided by a-c. short-circuit current.

Substituting values in this equation we have $N = 90$, which serves to explain that the characteristics of the machines are such as to make them inherently sensitive to pulsations ranging from 90/1.4 to 90/0.7 per minute. The engine speed noted above lies within these values. But notwithstanding this close agreement the fact is, that commutating poles undoubtedly work against converters operating on a-c. circuits subjected to pulsations or frequent and periodic disturbances, and bar from consideration the use of reciprocating units at customary speeds

*Modified formula by Kapp published in *Electrotechnische Zeitschrift*, 1899.

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in connection with 600-volt, 60-cycle converters, for this pole is necessary, as pointed out above, for mechanical reasons.

## Efficiency

Because of reduced ventilation and the liberal use of copper and iron in the electrical and magnetic circuits, the efficiency of the converters is very high; being,

| | | | |
|---|---|---|---|
| at | 50 per cent full load | 91.8 | per cent |
| | 75 " " " " | 94.0 | " " |
| | 100 " " " " | 95.0 | " " |
| | 125 " " " " | 95.5 | " " |
| | 150 " " " " | 95.8 | " " |
| | 200 " " " " | 95.0 | " " |

Best efficiency at 194 per cent full load.

These values are test results and include all losses. Sixty-cycle transformers are also very efficient, and in consequence the overall conversion loss is low. For a period of one month the substation efficiency is as follows:

| | |
|---|---|
| A-c. input to substations | 3,986,880 kw-hr. |
| D-c. output at converters terminals | 3,667,930 " " |

$$\text{Ratio} = \frac{3{,}667{,}930}{3{,}986{,}880} = 92 \text{ per cent}$$

This experience in the use of 60-cycle, 600-volt synchronous converters in railway work may be summed up as follows:

1. Pulsations in a-c. supply circuit must be entirely eliminated.
2. The design must include in addition to the commutating pole, liberal proportions of iron and copper, notwithstanding the high speed.
3. Field dampers must be very low in resistance and bridged to permit of a-c. starting.

The advantages accompanying the use of 60-cycle apparatus are apparent to all and include, briefly, standardization of frequency, low cost and high efficiency.

## APPENDIX I.

Extracts from agreement between The Cleveland Electric Illuminating Company and The Cleveland Railway Company, March 29, 1912.

For the purpose of this paper it is only necessary to call attention to paragraphs (c) and (d) of section nine, relating to power factor. This provision imposes a limitation upon the design of

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a compound-wound synchronous converter of considerable importance in affecting heating in the armature winding, and consequently the capacity under which standard converters are customarily rated, would be much impaired when operated so as to maintain 100 per cent power factor at the primary terminals of the transformers.

SECTION NINE

Paragraph (c)—The Railway Company guarantees that the monthly average power factor at each of the Power Company's supply stations shall be maintained at not less than 90 per cent and it is mutually agreed that if the monthly average power factor at any supply station differs from 90 per cent in any month, then the demand for that month shall be corrected and determined in accordance with the following formula:

Kilowatt demand is measured, divided by average power factor of load, and multiplied by guaranteed power factor of load: And that the demand on each station shall be increased or reduced accordingly, before computing the aggregate demand.

Paragraph (d)—The average monthly power factor shall be determined from the ratio of the sums and differences of the groups of single-phase watt-hour meters installed on each supply circuit in accordance with the formula, $\frac{W'-W''}{W'+W''} \times 1.732 =$ tangent of average monthly angle of lag, from which both the angle of lag and its cosine, which is the power factor, will be determined.

## APPENDIX II.

EXTRACTS FROM SPECIFICATIONS OF SUBSTATION EQUIPMENT

*General Information.*

The substations (in which the equipment specified below is to be installed) will be located in residential districts of the city of Cleveland and neighboring suburbs, as follows:

* * * * * * * * * * * * *

*Capacity of Substations.*

1. Windermere Substation, three 1500-kw. units as specified hereinafter.

2. Harvard Ave. Substation, three 1500-kw. units as specified hereinafter.

3. West 117th St. Substation, three 1500-kw. units as specified hereinafter.

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4. West 25th St. Substation, two 1000-kw. units as specified hereinafter.

*Equipment:*

The contractor shall furnish, deliver and erect complete in every respect on the purchaser's foundations and ready for use when connected to the purchaser's switching devices, cables and connections:

Nine 1500-kw., 514-rev. per min., six-phase, 14-pole, 600-volt d-c. compound-wound, 60-cycle, synchronous converters, equipped with commutating poles, mounted on self-contained bed plates, including the necessary single-phase, air-blast type static transformers, all in accordance with the following specifications.

Two 1000-kw., 600-rev. per min., six-phase, 12-pole, 600-volt, d-c. compound-wound, 60-cycle, synchronous converters equipped with commutating poles, mounted on self-contained bed plates, including the necessary single-phase air-blast transformers, all to be in accordance with the following specifications.

*Armatures:*

The ventilating ducts, and the general construction of the spider and fixtures, shall be designed with the object in view of minimizing all unnecessary noise such as vibrations, humming and high-pitched windage tones. The converter station in every case will be located in an important residential section of the city where all such noise must be avoided.

The grouping of armature coils per slot in the armature winding shall consist of such an arrangement that the average voltage between adjacent commutator bars shall in no case be less than 13.3 volts, nor more than 14.3 volts.

Equalizer taps shall be brought out from the end of at least every other armature coil and interconnected with all other coils of the same potential, to provide a thorough balance throughout the armature.

The commutators must have the mica slotted or grooved out to a depth well below the surface of the commutator bars.

The d-c. brushes of all converters must be equipped with a suitable brush-raising device to permit of lifting the brushes from the commutator while starting the converters from $\frac{1}{3}$–$\frac{2}{3}$ full-voltage connections, to be provided in the secondary circuit of the transformers.

*Field Dampers:*

Only the main field poles shall be provided with heavy copper field dampers, properly arranged to provide full damping effect

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to the main fields without disturbing in the least the sensitiveness of the commutating pole, in order to provide for the best possible operating characteristics.

*Collector Rings:*

Because of the high speed, the collector rings shall be equipped with composition copper brushes and suitable pig-tail connections, instead of the laminated type of collector ring brush ordinarily used in the past.

*Current and Flux Densities in Armatures:*

The current density in the conductors comprising the armature winding must not exceed an average of 3500 amperes per square inch, based upon d-c. output at rating, *i.e.*, considered as d-c. generator.

The flux density in the teeth of the armature core shall not exceed 130,000 lines per square inch, and the density in the core shall not exceed 65,000 lines per square inch, based upon d-c. output at rating.

The current density per square inch of brush surface must not exceed 42.5 amperes at rating.

*D-C. Voltage Regulation:*

All the converters herein specified shall be compound-wound with sufficient series field effect to produce only approximately constant 600-volt direct-current voltage. The reactance to be provided in the transformer shall be approximately 8 per cent in order to provide for a total reactance of 12.5 per cent including converter, transformer and leads.

*Performance:*

After a run of 12 hours at full load at 600 volts, d-c., the temperature rise of the different parts of the converter shall not exceed the following:

| | | |
|---|---|---|
| Armature | 35 | deg. cent. rise by thermometer. |
| Fields | 35 | " " " " " |
| Commutator and collector rings | 35 | " " " " " |

With the load then increased to 50 per cent overload (150 per cent rating) at 600 volts d-c. for two hours, the temperature rise of the different parts of the converter shall not exceed the following:

| | | |
|---|---|---|
| Armature | 55 | deg. cent. rise by thermometer. |
| Commutator and collector rings | 55 | " " " " " |

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The above shall be based upon a power factor ranging from not less than 0.98 leading or lagging to 1.00, and on 25 deg. cent. for the temperature of the surrounding air and normal conditions of ventilation. In the event of the temperature of the surrounding air differing from 25 deg. cent. the observed rise in temperature will be corrected by ½ per cent of each degree cent. that the temperature of the surrounding air differs from 25 deg. cent.

*Insulation Test.*

A test to determine the value of the insulation will be made after the converters have been erected by the contractor on the premises of the purchaser, as follows:

The insulation between core and armature conductors must withstand successfully, a test of 2000 volts at 60 cycles, for 60 seconds. The insulation between the frame of the converter and the shunt field circuit must withstand successfully a test of 5000 volts at 60 cycles for 60 seconds.

*Efficiency:*

The efficiency of both the 1000-kw. and 1500-kw. converters shall be as follows:

| | | |
|---|---|---|
| 150 per cent of rating | (50 per cent above full load) | ..95.7 per cent |
| 125 " " " " | (25 " " " " " ) | ..95.0 per cent |
| 100 " " " " | (full load ) | ..94.5 per cent |
| 75 " " " " | (25 per cent less than full load) | 93.0 per cent |
| 50 " " " " | (50 " " " " " " ) | 90.5 per cent |

In testing for efficiency all loss including those in the brushes in commutator and collector ring will be taken into account.

*Flash-over Test:*

The synchronous converters to be supplied under this contract will be subjected to the following test to determine their freedom from the tendency to flash over. Starting at no load, 100 per cent overload (two times rating) will be thrown on instantly by means of a storage battery and the converter must withstand this test satisfactorily without hunting, destructive sparking, or flash-over. Likewise, beginning with 100 per cent overload (two times rating) the d-c. current breaker will be tripped and the load instantly removed. Under this circumstance the same performance with respect to hunting and commutation as above, will be required.

*Fittings and Supplies:*

Each and every synchronous converter shall be equipped with:

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One end play device (oscillator), d-c. end converter.

One speed limiting device, a-c. end converter.

One equalizer switch mounted on panel fastened to converter frame.

One suitable shunt field break-up switch fastened to converter frame.

One suitable inductive shunt for commutating pole field circuit.

One suitable non-inductive adjustable shunt for commutating pole field circuit.

All necessary leads from brush terminals to equalizer switch, and to suitable terminal block, must be provided, including attachments for connecting in shunts and field terminals.

The collector ring brush collars and all studs on switches and terminal blocks, shall be equipped with terminals.

One shunt field rheostat box with terminal dial.

All the supplies and fittings supplied with each converter must be approved by the purchaser's engineer.

*Transformers:*

The contract shall furnish, deliver and erect complete in every respect on the purchaser's foundations, and ready for use when connected to the purchaser's switching devices, cables and appliances, seven single-phase, air-blast shell-type, 60-cycle, 11,000-volt primary voltage, 365-kv-a. transformers.

The contractor shall furnish, deliver and erect complete in every respect on the purchaser's foundations and ready for use when connected to the purchaser's switches, cables and appliances, 28 550-kv-a., shell-type, air-blast, single-phase, 60-cycle transformers, 11,000-volt primary winding.

The primary circuit of all transformers shall be arranged for delta connection and each provided with four 2.5 voltage taps. The secondary circuits of the transformers shall be suitable for diametral six-phase connections for the converters, and each transformer secondary circuit must be provided with $\frac{1}{3}$ and $\frac{2}{3}$ voltage taps for starting the converter.

The outside connections of the primary circuits must be extended by means of suitable leads to terminals in the bottom of the transformer case. All secondary taps shall end in terminals brought to the bottom of each transformer, the whole to make a neat and substantial arrangement for bottom connections.

One transformer of each size will be used as a spare unit and provision for its reception will be made in the substations.

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*Efficiency and Temperature:*

The efficiency and temperature of the transformers shall be in accordance with the best modern practise in respect to the type offered.

*Secondary Voltage:*

The voltage of the secondary circuit must be suitable for the converters hereinbefore described, as follows: When these transformers are connected in delta relation by means of the outside primary terminals and connected across an 11,000-volt, three-phase line, the converter d-c. voltage shall be 575 volts with normal shunt field excitation.

*Insulation Test:*

The insulation between primary and secondary winding and the frames and cores of transformers will be required to withstand successfully a test of the following voltages after erection:

| Primary Windings | Secondary Windings. |
|---|---|
| 22,000 volts, 60 cycles | 2000 volts, 60 cycles |
| for 60 seconds. | for 60 seconds. |

*Capacity:*

At the capacity specified hereinabove, and with the proper amount of ventilation ( which ventilation must be specified by the contractor) the transformers must have sufficient capacity to meet the overload requirements of the converters without excessive or destructive heating.

*Reactance:*

Approximately 8 per cent of inherent reactance shall be provided in the transformers for the purpose of interposing not over a total amount of 12.5 per cent of reactance in the circuit, including the transformer, leads and converter.

*Blowers:*

The contractor shall furnish, deliver and erect on the foundations in the substations:

Six three-phase induction motor-driven, directly coupled, steel plate blower sets, of the following capacity: 15,000 cu. ft. of air at one ounce pressure.

Two three-phase induction motor-driven sets same as above, with a capacity of 8000 cu. ft. of air at one ounce pressure.

Two blower sets to be installed in each substation; the smaller units to be supplied for the West 25th St. substation.

With each blower set the contractor shall supply an auto-

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starter, and the voltage of the induction motors shall correspond to the voltage of the secondary circuit of the main transformers to which they will be connected by the purchaser.

*General:*

Great care must be exercised in the designing of the equipment hereinbefore specified, to guard against undue noise. As stated above, it is anticipated that trouble will result from the operation of unnecessarily noisy equipment in the substations, which by necessity must be located in the suburbs of the city of Cleveland.

(The balance of the specifications covering foundations, painting and finishing, patents, guarantees, etc., follows along usual lines.)

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# FACTORS DETERMINING A REASONABLE CHARGE FOR PUBLIC UTILITY SERVICE

BY M. E. COOLEY

ABSTRACT OF PAPER

The paper considers the relations of the public to public service corporations and analyzes the construction and operating costs of the public utility plant upon which the rates for service should be equitably based. The hostility which frequently exists between the public and the officials of such corporations has been due largely to the past attitude of the officials of these corporations, who have frequently ignored the fact that they are doing business under a grant from the public which gives them a practical monopoly of such service, and that they should therefore be restricted to a reasonable amount of profit.

There is considerable ignorance on the part of the public in regard to the total elements of cost which enter into the construction and operation of a public utility plant, and all of these costs must be taken into account in establishing a rate which will give a fair return on the investment and at the same time the best service possible under existing conditions. The various items of expense which make up the total value of the property as a going concern, the cost of operation, depreciation, discount on bonds, etc., are all considered, their total forming the basis upon which the rates for service must be figured.

PROBABLY no question of greater importance confronts our people today than the relations of the public and the public service corporations. I refer to relations of a domestic character, rather than foreign, those which affect us as a nation considered as a family in which the interests of all of its members are, or should be, entwined, interwoven, in such manner that whatever is good for one is good for another.

Naturally in treating my subject I shall have in mind ideals which may require years for their realization, but I shall hope to appeal to you with arguments based so firmly on actual facts that I shall not be accused of being academic. I shall endeavor to throw upon my subject the light of nearly fifteen years of experience in the investigation of public utility properties, and I shall hope to leave with you the impression that my views have been expressed with due regard to proper perspective. That is to say, I shall hope to avoid being accused by anyone of even *appearing* to favor one side of the question as against the other. My desire is to speak of what may be



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seen from the hilltop by any one who will divorce himself from the interests of either side, and try to look upon the problem with unbiased vision.

There are, of course, two sides to this question, as there must be in order that any question can exist. There is the side of the public and the side of the public service corporation. Today they are wide apart. They are wide apart for one principal reason, namely, ignorance. While it may be no disgrace to be ignorant, it is disgraceful to remain ignorant when so little education is required to dispel it. The education required is not difficult; indeed, it is very simple; but the trouble is that very many of those who most need it are not willing to be educated. Various motives exist, which I will not discuss here, further than to mention that chief among them is a spirit of antagonism, akin to revenge on the part of the public, in localities where the opportunity exists for its manifestation.

It is,.I believe, generally considered by the officers of public service corporations that they are, or rather were, themselves responsible for the unfriendly attitude of the public toward them which is now almost general in this country. The public service corporation has in the past proceeded on the theory that the words *public service* had no particular meaning, and that like any other corporation it was at liberty, and indeed had the right, to make as much money as possible out of its business. The public service corporation has in the past ignored the fact that its right to do business is a public grant, a grant which in the very nature of it precluded others from engaging in the same business in the same locality. True, in theory at least, others might be admitted to the field and thus create competition, but practically it has not worked out that way. Ordinarily there is not enough business for two, and even if there were, great inconvenience is likely to result; as for instance in the use of two telephone systems, two waterworks systems, and several street car systems in the same city. It is much to the advantage of the public, both in convenience and expense, to have a single utility of the different kinds serve it when that service can be had on fair terms.

What are fair terms? That is what is partly meant by the words *reasonable charge* in the title of this paper. I say *partly* meant. In the broad sense they may be synonymous. To illustrate: The service rendered by a public service corporation may be very poor without any good excuse for it.

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In such a case a reasonable charge would be less than when the service was entirely satisfactory. Careless or unintelligent management, or a desire to increase the dividend rate, would lead to this result. Again, the service rendered may be very poor and yet be the best possible and keep the business alive; that is, were the rates higher a better service could be rendered. This may be found in small towns where the extent of the business will not support anything better. Further, the service may be very unsatisfactory and still be the best possible to render regardless of rates; that is, physical conditions may limit the ability to render satisfactory service. This may be found in large cities, an example being a street railroad system which can not be extended except by building elevated or underground systems.

Fair terms, then, means fair service, or the best possible under the conditions, to the public on the one hand, and a reasonable charge for that service to the corporation on the other hand. They are, or should be, the two members of an equation which are equal to each other. Like an equation, given the service demanded and certain other factors involved, the fair rate, or the reasonable charge, can be readily determined. It is these factors we come now to consider. They embrace, first, the capital investment upon which the interest return is made either in the form of interest or dividends, or both; second, the operating expenses which include maintenance and repairs of all the elements of the physical property, and taxes; third, a depreciation fund out of which can be replaced elements of the physical property which are worn out, or have become obsolete, so that they can no longer be used economically; and fourth, a sinking fund to provide for the loss of the capital due to depreciation, or the difference between the cost of the property when new and when disposed of at the expiration of its franchise life. Let us take them up in order, capital investment first.

It should be understood at the outset that no capital can be made available for a public utility, or for any other business, for that matter, without a sufficient return on the money to tempt its investment in the business. Capital obeys the law of supply and demand like any commodity. Thus, if capital be invited for investment in a service which is desired by the public, then the public must expect to pay the price in the form of interest or dividends which is necessary to secure it.

However much in the past capital may have been tempted

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into the field without invitation in the hope of large returns, those days are rapidly disappearing; and before very long, if not now, we shall be obliged, not only to extend an invitation, but to offer inducements to bring capital to our door. Those inducements must be not only a fair return on the capital investment but a welcome guaranteed throughout a term of years. Capital may be compared with the guest in our household. While she bides with us she is entitled to the treatment accorded to a guest. She may have worn out her welcome but at the same time have become indispensable to our domestic affairs, so that we must continue to suffer her presence. We, the public, cannot invite the guest and then while she is with us slap her face; on the other hand, the guest cannot with impunity proceed to rob us once she is in our home.

There is at present a very natural distrust on the part of the public. Capital in the past having very often been self-invited, and having been at first welcome, then tolerated, has finally worn out both welcome and toleration. The logical result, one might think, would be to get along without capital. But of course that would be impossible. Whether the utility be built and operated by the public or by a corporation, capital is necessary. It is true that for a municipally owned utility capital may be had on more favorable terms with the security which the public can offer; but it does not follow that the service rendered *would* be at correspondingly low rates or reasonable charges. It *could* perhaps, but the experience of the past favors the belief that such expectation would be utopian rather than practical.

The time is coming, if not already here, when it will make no difference whether capital be invested under the direct security afforded by a municipally owned utility or the more indirect security afforded by a franchise to a corporation. This time will have arrived when the public comes to understand the elements of cost, and all of them, which enter into the construction of a public utility plant. Those elements of cost are the same, or substantially the same, whether the plant be constructed by the public or by the corporation. The public must have a board intrusted with the construction and management of the utility. This board corresponds practically to the corporation's board of directors.

The board, whichever it may be, becomes the agent of the public. It makes the preliminary investigations, employs legal counsel, real estate men to procure the necessary right-of-way,

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conducts condemnation proceedings, obtains property consents, and attends to all matters connected with the proper launching of the project. It employs engineers to prepare the plans and specifications, invites bids, awards the contracts, and looks after the work during the construction period. It makes arrangements for the necessary funds to finance the project, the necessary working capital, and finally, after the work of construction is completed, puts the plant into operation.

Before its work has been done completely, the business must be thoroughly established; that is, converted from an inanimate to an animate condition. The earnings from operation must as speedily as possible be brought to a point where they will support all of the expenses. During the period of insufficient earnings, the deficits must be cared for. When the earnings become sufficient to meet all expenses, including interest on the cost of the property, the utility may be said to have become fully a *going concern.*

In all of this work the duties of the board or city officials representing the public, or of the officers representing the corporation, have been the same. The elements of costs have been the same. The principles involved have been the same. The only difference has been one of degree on some of the items, as for instance, less difficulty, possibly, in securing rights-of-way, and more favorable terms in financing. But as already stated, these advantages may in the ultimate results be more *apparent* than *real.* That phase I have no intention of discussing in this paper.

The principal cause of the difference of opinion between the public and the public service corporation, as I have come to see it, lies in the failure of the public to comprehend all of the elements of cost entering into the construction of a public utility plant. Not only that, but a failure also to understand all of the elements of expense which must be incurred in operating the property and maintaining its integrity, once the plant has been built and the business established. The corporation itself is only beginning to understand some of these things. Its officers intrusted with the management of the property have been obliged to make the best of things, striving on the one hand to earn the dividends called for by the stockholders, and on the other, to maintain the property so as to give satisfactory service. Without in any way excusing the corporation from its sins of the past, or of the present where they still exist, the trouble is now

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understood by the corporation, partly at least; and it must be conceded, I think, that just at present the fault lies more with the public than with the corporation. Let us now take up the elements of cost constituting the capital investment.

It will be easier of understanding if individuals will consider themselves a party to the enterprise. Assume for instance, that you are one of a number of men brought together to consider the building of a public utility property. What is the first step? Naturally you will all want to know whether the project is feasible. This will always involve preliminary investigations, the sounding of public sentiment to know to what extent the proposed service would be demanded, what concessions would have to be obtained in the matter of property consents and the conditions under which a franchise could be obtained. If these inquiries have resulted favorably, the next step would be to employ engineers to look over the field and make preliminary estimates of cost and determine upon the feasibility of the project. With the information thus far accumulated the bankers must be consulted to determine whether the necessary money can be had. At this point the project may fall through, as there may not be a sufficient promise of financial return to induce capital to come into the enterprise.

All of this preliminary investigation has involved expense which must be borne by someone. It may run from 0.2 to 0.5 per cent of the cost of the proposed property. In case of failure to go further it would fall upon the individuals taking part in the investigation. They have gambled and lost. But should the future promise be great enough to interest capital *mildly*, let us say, then the banker might be induced to gamble a bit, and by being given sufficient odds in the way of discount on bonds and blocks of capital stock depending for their value on future earnings, be induced to come in. The less of gamble there may be, the less the odds demanded by the banks; but at the present time these keepers of the vital life of all business enterprises must, like the well-fed trout, have bait of some form on the hook to interest them at all. Not so, however, with the rank and file who, like the hungry bull-head, bite at anything, even in the dark, if only the light of a candle be exposed to show in the faintest outline the nature of the bait. But public utility properties for the most part are not financed by the rank and file, but by bankers and trust companies. It is, therefore, a real " condition, and not a theory ", which confronts the promoter when he seeks to finance a proposition.

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If finally the preliminary work has resulted in the determination to proceed, there comes the organization of the company, the employment of legal counsel to draw up the necessary papers, the procuring of franchises, the obtaining of the necessary property consents, the securing of the right-of-way, by purchase or otherwise, the employment of engineers to make the final surveys and prepare the plans and specifications, the bidding and award of contracts. The actual work of construction then begins.

It is at this point that the public conceives the cost of the property to begin; and for the reason that the average citizen, skilled as he may be in the work of his own pursuit, has little or no knowledge of the skill required in another's pursuit. Yet this average citizen must be consulted because the project is a public utility. It furnishes him heat, light and power, transports him to his business, and provides him with other fixed necessities of life. This being so, let the condition be met, and first of all let this average citizen be educated to understand the requirements which must be met if he is to be furnished these necessities of our modern civilization. Once he understands there will not be, so far as he is concerned, any further trouble. The average citizen is fair-minded, and asks for only the square deal.

There is, however, another type of citizen who, however much explaining there may be, persists in seeing things his own way. He may be a self-appointed guardian of the people's interest; sincere enough and honest enough, but too often his zeal results in confusion of understanding, if not perniciousness. Another type belongs to the political class. He sees gain in one form or another if he can keep alive the troubles between the public and the public service corporation.

There is no greater service to be rendered the people of our country today than that which could be rendered by the newspapers if they would but go at this matter with the idea of acquainting their readers with the facts on both sides. I mean that they should not treat the quarrels between the public and public service corporations as items of news merely, but detail men on their staffs to make a study of the question involved, bringing to their aid the skill of the accountant, the engineer, the manager, the public officers entrusted with the affairs of these corporations, the business man, and the man who has devoted a lifetime, it may be, to a study of this class of problems. This work should not be done in a haphazard manner, but

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systematically and with one object in view, namely, to bring about as speedily as possible a clear understanding of all the facts on both sides. Such a work by our newspapers would not only add to the sum total of our happiness, but promote the prosperity and welfare of the communities which they serve. I sometimes wonder why the proprietors of newspapers do not see that their own business is in the nature of a public utility, morally at least.

It is perhaps unnecessary to refer in detail to all of the different items entering into the cost of the physical property of a public utility. Such items as the following are in general capable of being classified in an inventory, and are readily understood:— Land for railroad rights-of-way, electric transmission lines, and pond flowage; land for the many kinds of buildings required, such as office and station buildings, round houses, car barns, power houses for steam and hydraulic plants; and for reservoirs, dams, waterworks, and gas plants. The buildings themselves, together with their furnishings and fixtures. The roadbed, rails, ties and bridges of a railroad; and the locomotive, passenger and freight equipment. The dam structure, water wheels, and generator of a hydroelectric plant. The boilers, engines and generators of a steam plant. The tunnels and pipe lines of a heating plant. The pumping engines, water mains, hydrants and distribution system of a water works. The machinery, gas holders, and distribution system of a gas works. The conduits, manholes and distribution systems of electic lighting and power plants. The switchboard, machinery and apparatus of a telephone exchange; and the wires, pole lines, conduits and instruments of the distribution system. All of these items, and vastly many more, make up the physical structure of public utility plants. They are tangible, that is, they can be seen, counted, measured, weighed, and their costs determined. Materials and labor are the principal items in their creation and installation.

The plans and specifications of a utility plant having been completed, proposals for its construction are invited. The contractor figures the cost of every item as nearly as possible, adding various percentages to cover contingencies, that is, unforeseen difficulties of construction and oversights, some large and some small. He adds the costs of the necessary permits, the insurance required on the men employed and on the buildings during their construction; and finally adds another percentage

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on the whole for his profits. The propriety of these percentages in figuring the cost of work in advance is so apparent as to cause wonderment that any question should ever have arisen as to the equal propriety of including them in making an appraisal of a property at any time after it was built. Happily this ignorance concerning many of the physical elements has been dispelled, and there no longer is any question of allowing the necessary percentages to cover contingencies, insurance, contractors' profits, engineering and superintendence.

In amount the contingency percentages, varying on the different things from 2 to 20 per cent and upwards, may be assumed to average not less than 10 per cent. One half is usually applied directly to the items themselves, the other half as a percentage on the total cost of all the items. Insurance varies from 0.5 to 1 per cent. The contractor's profit should be estimated at not less than 10 per cent. Engineering and superintendence, like contingencies, varies with the different items from 2 to 10 per cent and over, an average being, say, 5 per cent. One half is applied directly to the items themselves, the other half, as a percentage on the total cost of all the items, including the contingencies and contractor's profits. If the insurance has not been included with the contractor's costs, it should follow after engineering and superintendence, and may then be combined with taxes in a percentage varying from 0.5 to 3.5 per cent. In the application of these percentages, only the *general* engineering percentage should be applied to land, the cost of which embraces its own particular expenses of acquiring, including damages, deeds of transfer and the like.

In case the contract has been awarded to a general contractor he may sublet the different parts to other contractors, each of whom includes in his bid contingencies and other items proper for his particular part of the work and his profits. In such cases the cost of the plant includes, besides the contingencies and profits of the sub-contractor, similar items for the general contractor. A general contractor responsible to the owners for the success of all building operations would probably demand and receive not less than 10 per cent of the cost of the entire work covered by his contract; and instances are known where the general contractor's profit has been large, 20 per cent or more. The measure of his profit is usually determined by the nature of the work, that is, the difficulties and uncertainties involved. The building of the Detroit River Tunnel is an example of where the general

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contractor made a large profit; but the uncertainties were such that it was not known in advance whether his profit would be large or small, or whether there would not be an actual loss.

Another method in vogue is to place all building operations in the hands of an engineering firm which makes all surveys, prepares the plans and specifications, and superintends the work from start to finish, making a charge therefore of 10 per cent on the actual cost of the work. This virtually amounts to a profit of 10 per cent, as the cost on which the percentage is based usually includes the salaries and wages of the men employed in the engineering work, and all traveling and office expenses as well. It is known as the " cost plus a percentage " plan. The engineering firm may be likened to the general contractor with this difference: The former takes its percentage on actual costs determined after the work is completed; and the latter, on the estimated costs made before the work is begun. Obviously the uncertainties involved would cause the general contractor to guard himself by making liberal estimates.

We come now to discuss certain other expenses chargeable to capital, but which are not so well understood. Taxes during the construction period is an item usually overlooked by the public. Obviously, any real estate acquired by a corporation for public utility purposes would be taxed the same as similar property owned by an individual. Taxes not infrequently are also imposed on structures built, even before any use is actually made of them. One very common error of the public is to assume that if municipally owned there would be no taxes on a public utility property. True, there would be no taxes levied directly against the property, but there would be the indirect taxes which every taxpayer would have to meet. To illustrate: A public service corporation has to pay certain taxes on its property, and they may be very large. If this property be acquired by the city, it bears no taxes. The same amount of money being required to meet the expenses of government, after as before, it follows that the citizens must make up the amount formerly paid by the corporation. If, however, the earnings remain the same, there will be money to pay the taxes out of earnings. But in that case presumably the rates of charges for service would remain the same, so that one of the alleged benefits of public ownership would disappear. The item of taxes is, in an appraisal, frequently combined with insurance, the amount of the item then varying from 0.5 to 3.5 per cent.

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The item of organization, administration, and legal expenses usually follows insurance and taxes and precedes interest during construction. As used by some, the term is rather elastic in being made to include all preliminary expenses, costs of promotion, certificates of necessity, mortgage tax, fees of incorporation, securing of franchises, and other general expenses. It is usually expressed as a percentage varying from 2.5 to 5 per cent, being applied to the sum of all preceding costs, including lands.

There arises in connection with many utility projects certain expenses which have come to be known as costs of promotion and promoter's profits. The terms themselves are rather infrequently used in appraisals, these expenses, if considered at all, being included under costs of administration. Administration is frequently combined with organization and legal expenses. Whatever may be said for and against costs of promotion and promoter's profits in the sense that they represent intangible elements in the nature of " rake-offs ", there are, in a totally different sense, certain expenditures during both the construction period and the early operative period which are legitimate and necessary and best described as promotion costs. In the sense that a promoter forwards, advances and encourages, that is, contributes to the growth, enlargement and excellence of a utility project desired by the public, there can be no question that such costs are entitled to consideration in determining a reasonable charge for service.

As to a promoter's profit, its propriety may possibly be decided by considering to what extent one would be willing to contribute to a project, independent of its construction cost, to procure its establishment; or, were a utility now serving the public in some necessary capacity to be taken away, to what extent would you, as one served by it, be willing to contribute rather than lose it. Put it another way: A man says he can make a success of a utility the citizens want, or now have. You doubt its possibility but consent to a trial, and he does it. How much are you willing to compensate him for his energy and brains? This implies a conception free of bias, broad-gaged and just to all interests concerned, which can be had only by being fair and open-minded, and by carefully refraining fron reaching any conclusion in advance. Obviously no percentage could be given for promoter's profits, but appraisals in which the costs of promotion have been ascertainable indicate that a proper

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charge may be as much as 2 per cent. Its allowance must depend on circumstances, and if included as a separate item, it must of course be excluded from administration costs.

Interest during the period of construction is an important item often overlooked in the past. This means simply that the money which has been expended from time to time during the progress of the work cannot be had without interest. If borrowed, it is secured by interest-bearing notes; and if provided through the sale of bonds, these bonds bear interest. Ordinarily, the interest charge is based on the assumption that the money expended starts at zero, and mounts uniformly to the total at the end of the construction period. Thus the rate of interest is applied to one-half the total cost, or one-half the rate is applied to the total cost. The construction period varies with different kinds of property, one year, two years, and three years being common lengths of time. It extends to the time when the property is put into operation and begins to earn. A rate of 6 per cent per annum is usually assumed.

The management of a public utility requires a home for its officers and the necessary furniture and fixtures. These may be rented, in which case the rent becomes an operating expense; or the company may own its offices and furniture and the special fixtures needed for its business. The cost then becomes a capital charge. In large properties, street and steam railways particularly, the offices, furniture and fixtures are frequently items of considerable expense. The cost of the equipment of offices, if incurred at the end of the construction period, does not involve interest during the construction period and the item can follow this interest. If, however, it has come earlier, its cost should enter into the sum on which interest during construction is computed.

Certain necessary stores and supplies must be provided ready for use in emergencies before the property can be put into operation. After the plant has been in operation for a time, these gradually adjust themselves as to quantities of the various items. The money represented by stores and supplies can bear no interest unless it be incorporated in the capital, or be carried as a floating debt. In either case the interest on this money becomes a proper charge against earnings. The amount considered is usually an average taken from the books.

Another item which occasions surprise is working capital. By this is meant the money which must always be available to pay

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bills, labor and the ordinary expenses of operation, and which in the very nature of the fund cannot bear interest except it be incorporated in capital, or be borne as a floating debt with interest paid out of earnings. In either case it becomes a charge against earnings, and therefore takes part as a factor in determining reasonable rates or charges. As between a capital charge and a floating debt it may be pointed out that as a capital charge the rate of interest would presumably be less than as a floating debt. A working capital is as necessary an expense as any other in the production of a public utility property. Without it the business for which the property was constructed could not be done. How often have we known of the failure of apparently good business enterprises merely for the lack of sufficient working capital. The amount of working capital, like stores and supplies, is usually an average taken from the books.

We have now reached the point at which the property has been completed, having considered items, all of which may enter into the capital investment, and are ready to take up the *second* principal factor, namely, operating expenses. With a working capital to hand, the property has been put into operation. It begins to earn, but a considerable time must elapse ordinarily before the earnings from operation suffice to meet all of the expenditures. By all of the expenditures I mean, interest on the cost of construction, taxes, operating expenses, a fund out of which the expenses of maintaining the integrity of the property can be borne, and another fund to provide for losses of capital at the end of the franchise period. These latter I will discuss separately under the head of "Depreciation" and "Sinking Fund", respectively. During this period of insufficient earnings, money must be borrowed to make up deficits; not only that, but interest must be paid on the borrowed money until the time that the earnings suffice to meet all expenses. This accumulated deficit constitutes what may be termed the cost of procuring a going concern; in other words, the cost of establishing the business. Were the property to change hands at the time the earnings just suffice to pay all expenses, the cost of establishing the business would become the going concern value of the property, and be a part of the total value of the property as a going concern *at that time*. It is a difficult element of cost to determine satisfactorily, in the absence of well-kept accounts, starting with the property itself.

Not infrequently the point is made that the longer it takes to

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establish the business, that is, the greater the sum of its deficits in earlier years, the greater is its value as a going concern. This apparent inconsistency is explained by the fact that these deficits are real costs, and necessary if the utility is to be had at all. The utility being a necessity, it must be supported by the public the same as any other necessity. The cost of establishing the business therefore becomes a factor in determining reasonable rates or charges. This cost, like that of working capital, if incorporated in the interest-bearing capital, becomes less of a burden against earnings than if carried as a floating debt.

Probably the least understood factor of expense in connection with a public utility property is depreciation. I have called this the *third* factor in determining a reasonable charge for public utility service. By depreciation I mean the money required to to be paid out of earnings in order to meet the expenses of maintaining the integrity of the property. Depreciation is the result of wear and tear and exposure to the elements. It also includes the replacement of machinery which, while not yet worn out, has become obsolete; that is, no longer economical to use; or if still economical, no longer satisfactory to the public. Depreciation includes, further, the wrecking of the machinery due to accident, or to the acts of God.

In the building of a public utility property all of the elements are originally new, but as time goes on these elements suffer wear or decay, some in one degree, some in another. When an element has become worn to a point where it is no longer profitable to keep it in service, it is replaced. Thus in time we have a property which as a whole is made up of old and new elements, the condition of which in the aggregate is something less than the first cost of these elements new. In the very nature of the property it is impossible ever after it is once started to have present in it the full 100 per cent represented by all new elements. It can, however, be maintained in some condition less than 100 per cent, and it is usual and necessary to maintain it at a point which will enable the most satisfactory service to be rendered with the smallest expense consistent with satisfactory service. This point may be anywhere between 80 and 90 per cent, depending on the kind of property.

The expense necessary to keep an element in service during its useful life is a plain operating expense classed under maintenance and repairs, and is not included under depreciation as I am describing it. The depreciation fund is properly a separate fund,

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maintained as such as distinctly as an interest fund. It is the fund which insures the prolongation of the life of the property indefinitely and always in a condition to render satisfactory service. It is not, however, a fund out of which additions, extensions or betterments may be made, which in their nature constitute additions to capital.

Thus understood, depreciation becomes a factor, and indeed a very important factor in determining reasonable charges for public utility service. Unhappily, the practise of providing this fund is not uniform with the different utilities—not uniform either in principle or practise. It has long been common for some utilitjes, railroads for instance, to wear down in lean years and build up in fat years. Thus the condition of the property is not maintained in some uniform condition expressed as a definite percentage of the cost of all new elements, as for example, 80 per cent, but may vary all the way from 75 to 85 per cent.

It is commonly believed by the public that a utility property should not be permitted to earn on more than the so-called present value of its physical elements; that is, their cost new less depreciation, say 80 per cent of the cost new, or less. As bearing on this I have pointed out that the property, which by means of a proper depreciation fund can be maintained at some definite percentage which enables it to render satisfactory service, has cost 100 per cent. That is, the 80 per cent property can not be had at all without expending the 100 per cent. Thus in order to have an 80 per cent physical condition, we must have a capital charge of 100 per cent. From this it becomes apparent that in determining a resonable charge we must base it not on the percentage which represents condition, but on the cost of the property which cannot be maintained economically above an 80 per cent condition.

If, however, it be insisted that only that percentage of the total cost which is represented by the maintained condition of the property can bear an interest return, the loss of capital and interest thus incurred must be provided for out of earnings in another way, namely, by a sinking fund. This, then, is the *fourth* factor determining a reasonable charge for public utility service. It is to be borne in mind that in this entire discussion I am assuming only actual costs in the capital investment, and only such an interest rate as will induce the investment of the capital in the utility. At the end of the franchise period it is necessary to make good both principal and interest.

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The importance of this sinking fund and its magnitude depend on the attitude of the public towards the utility company. The public service corporation works under a franchise, which is simply a grant by the public of the right to do business. With certain kinds of utilities the franchise is perpetual, with others, the life is limited to a definite period, say, 30 years. In some states, Wisconsin for instance, indeterminate franchises are granted; that is, franchises which can be called in, or surrendered, at any time, subject to control by the Railroad Commission of that state. In the case of a limited franchise under which the utility company must cease operations and close up its business at the end of a definite period, the company must make not only enough to pay the interest on the cost of the plant and maintain it always in condition to render the service demanded by the public, as well as the operating expenses, including taxes, insurance and repairs, but also an additional amount to cover whatever part of the plant must be sacrificed at the end. This means a sinking fund to retire portions of the cost, if not the entire cost. In other words, the company must earn enough during its life to pay back whatever part of the principal has to be sacrificed, as well as the interest on the principal, in addition to maintaining and operating the plant satisfactorily during its franchise life.

This sinking fund is not always, indeed, I may say, is not generally, kept as a separate account, in this country; but is taken out in the form of distributed earnings from year to year in excess of the amount normally required as interest on the cost. Not infrequently what appears as an abnormally large dividend will on analysis be found to be only sufficient in the end to make good to the investor both the interest on his money and the principal sacrificed when the business is closed out.

It should be clear from this that in general a long term franchise is more favorable to the public, so far as charges for service are concerned, than a short term. To illustrate: assume that the plant must be sold for what it will bring as scrap or second-hand material; the difference between its cost and sale value must be made up out of earnings during the life of the franchise. Thus, if the franchise life be short, say 25 years, the sinking fund annuity must be much larger than if the life be 50 years. No annuity is required, when the life is perpetual. No doubt longer term franchises will be granted in the future, particularly now that the control of them is being lodged by the states in public service commissions.

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I am not discussing in this paper conditions which have existed in the past, or may exist, now, in connection with old properties, but am confining myself to fundamental things, those which should guide us in our future relations; those relations which will come to exist when the public service corporation is permitted to earn only enough on its investment to bring capital into the field; that is, the critical condition, as it were.

There remains for me only one more topic, and this I have put off until the last, always shying at it, and going around when possible. I refer to discounts and securities. This I have found: No bond house will even consider financing a public service corporation without a bond discount. I refer particularly to utilities built and operated under a limited franchise. It will have to be a good property to secure better than 15 per cent discount. It is an excellent property which commands as low as 10 per cent discount. The best discount I have ever come across in my own investigations is 8 per cent. This does not apply to municipalities, however, at least not to the same extent.

The simple conclusion is that if the public utility is a necessity and the money for it is obtained in the usual way, one element of cost is the discount on the bonds, which in effect starts the property off with some water in its securities. It is, or is not, water, as you view it. Anyhow it is necessary in the ordinary way of financing properties. Thus we are obliged, in determining a reasonable charge for public utility service, to consider not merely the actual cost as I have previously given it, but something more, namely, the face of the securities which command an interest return. Opinions differ on whether it is better for this discount to be absorbed as a capital charge or carried as an interest charge. So far as the purpose of this paper is concerned it is not material, as in either case there must be a charge against earnings to take care of the discount.

It will be convenient to bring together the several elements which take part in determining a reasonable charge for public utility service. Not all of them take part at the same time, necessarily, for some may appear in one case and not in another; or several may be combined in a single item. In a general way and in a somewhat natural order, they may be summarized as follows:

*First, Capital Investment.*

1. Preliminary costs covering investigations as to feasibility of project.

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NOTE.– Organization, promotion, administration, and legal expenses, engineering and superintendence during construction, which are distributed over the whole period of construction, are more conveniently placed later in the schedule.

2. The physical property; the several items making up the whole arranged in order, each affected with its proper allowances to cover contingencies, special engineering, and other costs peculiar to the item; land first, followed by clearing and grubbing, then the various structures and equipment; sub-contractors' profits included with separate items.

3. General contingencies applicable to the property as a whole as distinguished from special contingencies applicable to particular items.

4. General contractor's profits; or, the profits to an engineering firm building the property on the " cost plus a percentage " plan.

5. General engineering, and superintendence during construction.

6. Insurance and taxes.

7. Organization, administration, and legal expenses.

8. Cost of promotion, and promoter's profits.

9. Interest during the construction period.

10. Office furniture and fixtures.

11. Stores and supplies.

12. Working capital.

*Second, Operating Expenses.*

13. Operating expenses *per se*; that is, salaries, wages, fuel and other supplies, repairs and upkeep; all expenditures required in rendering the service of the utility, including insurance and taxes.

14. Interest on the capital investment (the actual cost of the property), *i.e.*, interest on securities which must be paid regularly.

15. Interest on floating debts; this may include the discount on bonds, and the cost of financing, if these have not been incorporated with capital.

16. Cost of establishing the business; the sums of money required to be borrowed, with interest on the same, to make good the differences between the earnings and expenditures up to the time the earnings become sufficient to meet all expenditures. This may be made a capital charge, or carried as a floating debt to be paid out of future earnings.

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*Third, Depreciation Fund.*

17. The regular contribution to the depreciation fund, out of which the integrity of the property is to be maintained.

*Fourth, Sinking Fund.*

18. The annuity required to retire such portions of the securities as may be necessary at the expiration of the franchise life of the property, in order that the investor may receive back his entire principal when the business is closed out.

It will surprise everyone not familiar with the cost of building utility plants to learn that the so-called over-head charges are in the aggregate a large percentage of the costs of labor and the material things entering into their construction. An examination of the various percentages mentioned in discussing the elements of cost, omitting items 1, 4, 8, 15 and 16, will disclose that if the individual contingencies of construction, special engineering charges, and contractor's profits be assumed to be embraced in item 2, the total percentage may vary from 12 to 25 per cent; and if these inside percentages be added to the outside, or general, percentages, the total percentage may vary from 30 to 60 per cent.

It is to be regretted that engineers, and others who have had experience in building properties, and valuing them afterwards, have not done more towards disseminating knowledge of the actual conditions found in such work. We should then be much further along towards the mutual understanding which must exist before the public and the public service corporation can get together on common ground. But engineers have many times hesitated to use the larger percentages, fearing to be accused of favoring the corporation. They have preferred instead to secure the equivalent of them by using larger units of costs; or have used the smaller percentages, influenced by the feeling, unconsciously perhaps, that all things considered, the results were fair enough. In combining the judicial with their engineering function, they have unwittingly only obscured the issue. All too frequently engineers have felt obliged to exert themselves to the utmost in favor of their client, leaving the interests of the other side to be fought for with equal solicitude by an opposing engineer. Thus they have become advocates. This, in my opinion, is not the best way to handle these momentous problems. It would be far better in these troublesome times to throw open the blinds and let in all the light, our motto being *veritas vincat.*

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(*Subject to final revision for the Transactions*).

# POWER FROM MERCURY VAPOR

BY W. L. R. EMMET

ABSTRACT OF PAPER

The author describes a thermodynamic process using a mercury boiler in tandem with a steam-generating apparatus for the production of power. As mercury boils at 677 deg. fahr. at atmospheric pressure and condenses in a 28-in. vacuum at 455 deg. fahr., its temperature and pressure characteristics make possible the utilization of some of the energy available in ranges above those practicable for steam apparatus. The object of the new development is therefore to increase efficiency, by increasing greatly the temperature range available. The mercury vapor produced in the boiler passes to the nozzles of a turbine which drives a generator or other utilizer of power, and thence to a condensing boiler, where it is condensed to liquid mercury on the outer surface of tubes which contain water. The heat given up by the mercury vaporizes the water, and the steam produced is used to drive other turbines or for any other purpose. The author describes the experimental development of the mercury boiler, which is of such a design as to require the least possible amount of mercury. Means are provided to guard against the loss of mercury at any of the joints, and for immediately detecting any leakage if it should occur. The advantages and disadvantages of the process are discussed, and the most advantageous size of unit for commercial application.

THE THEORETICAL limit of efficiency in a thermodynamic process is the ratio of the temperature range embraced by the process to the maximum absolute temperature used, $\frac{T - T_1}{T}$. In all processes available for commercial power development, the lower limit is fixed by the temperature of cooling water available, and is therefore not susceptible of variation. The possible upper limit is the temperature which can be produced by our fuel when burned with air, which in practise is about 2700 deg. fahr.

The purpose of the process here described is to utilize some of the energy available in ranges above that which can conveniently be utilized with steam. The theoretical efficiency of steam processes can be increased by using higher pressures, but since with rise of temperature the increase of pressure is very rapid, and since the steam turbine has limitations in the



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efficient use of high pressure, prospects of gain in this direction are not very attractive.

Mercury boils at 677 deg. fahr. at atmospheric pressure and condenses in a 28-in. (711-mm.) vacuum at 455 deg. fahr. It is therefore well adapted, at least by pressure and temperature conditions, for use in a temperature cycle above that now used with steam. Its use to increase greatly the temperature range available, and so to increase efficiency, is the object of the development here described.

Before going further, the writer desires to explain that the principle involved in this process was suggested to him by Mr. Charles S. Bradley, who proposed and patented a quite similar process in which he intended to use certain other substances of high boiling point and relatively high vapor density. It has since been learned that there have been other proposals along similar lines, although none of them have involved the use of mercury. Consideration of the possibilities suggested by Mr. Bradley led the writer to study the characteristics of mercury, and from this study and a course of experimenting which has been going on for a year, the plans of procedure here shown and explained have been evolved. A set of apparatus suited to the production of about 100 h.p. has been nearly completed and it is hoped that experiments on a scale and of a character approaching commercial conditions may be made within a month or two. Anything so completely novel and so essentially complicated is naturally liable to delays, so that the prospect of successful tests cannot be confidently predicted. Since the process has been talked about and since a good deal of interest has been expressed, the writer has thought best to record his expectations and to make explanation of the plans which have so far been evolved.

In studying the thermodynamic possibilities of a substance like mercury, we proceed exactly as we do in the case of steam, and for the sake of convenience it may be well to give here some data relating to the subject.

| | | |
|---|---|---|
| Boiling point of mercury at atmospheric pressure | 677 deg. fahr. | (358 deg. cent.) |
| Boiling point of mercury at 28-in. vacuum | 457 deg. fahr. | (236 deg. cent.) |

Vapor density is in the ratio of atomic weight and absolute temperature; as compared with water the vapor density of

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mercury is therefore 6.56 times as great at the boiling point and 6.8 times as great at 28-in. (711-mm.) vacuum.

Specific heat of mercury liquid..... 0.0373
" " " gas, (constant pressure)..... 0.0248
(According to Kurbatoff; *Zeit. Phys. Chem.* 43, 104, 1903).

Latent heat of vaporization—
at 25 lb. (11.3 kg.) abs. $r = 117$ B.t.u.
" 15 " (6.8 kg.) " $r = 118$ "
" 28-in. (711-mm.) vacuum $r = 121$ "
" 29-in. (737 mm.) " $r = 121.5$ "
(Calculated from formulas by Kurbatoff).

The boiling point of mercury at various pressures is shown by an accompanying curve, Fig. 1, and curves are also given in Fig. 2 showing the energy theoretically available from mercury vapor within various pressure ranges. These curves are calculated from Rankine's formula:

$$E = 778\left[Q_1 - Q_2\left(1+\log.\frac{Q_1}{Q_2}\right)+\frac{x_1 r_1}{Q_1}(Q_1-Q_2)\right]$$

$E$ = energy in ft-lb.
$Q_1$ and $Q_2$ = heat of liquid.
$x$ = dryness factor.
$r$ = latent heat.

The data above stated may not have been as accurately determined as those which are available for steam calculations, but their substantial accuracy is indicated by the fact that in our experiments, the measured flow of vapor through nozzles has closely checked the calculations.

The method applied in this process may be stated briefly as follows: Mercury is vaporized in a boiler heated by a furnace of ordinary type. From this boiler (see Fig. 3) it passes at a pressure near or not much above the atmosphere, to the nozzles of a turbine which drives a generator or other utilizer of power. From this turbine it passes to a condensing boiler where it is condensed on the outer surface of tubes which contain water, and this water is vaporized by the heat delivered, and the steam produced is used to drive other turbines or for any other purpose. This condensing boiler is preferably placed at a level above the mercury boiler, so that the condensed liquid will run back into the mercury boiler by gravity without the aid of a pump.. Since the mercury vapor is much hotter than the steam, the gases will normally leave the mercury boiler at

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higher temperatures than they have in leaving a steam boiler. To utilize this excess heat in the gases, it is proposed to convey them first after leaving the mercury boiler through a heater which raises the returning liquid almost to the boiling point,

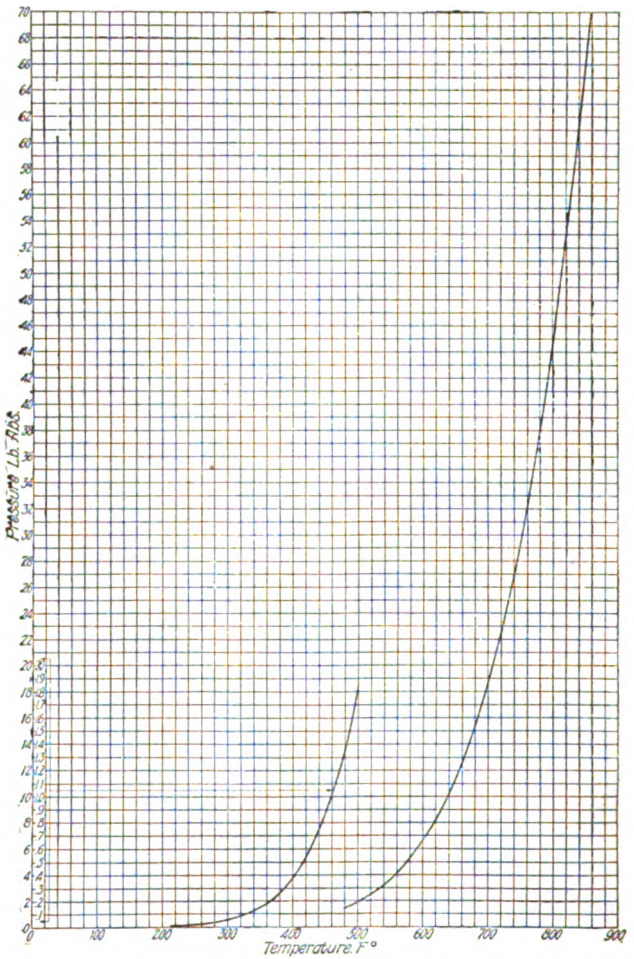


FIG. 1—CURVE SHOWING BOILING POINT OF MERCURY AT VARIOUS PRESSURES

second through a superheater which superheats the steam delivered by the condensing boiler, and third, through an economizer which heats the feed water for the condensing boiler and so reduces the gases to the lowest practicable flue temperature.

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By careful study and experimental development, which will be later explained, means have been devised for reducing the amount of mercury used, for effectively preventing its loss or dissipation, and for immediately detecting any failure in such prevention.

The disadvantages of mercury for such a process are: First,

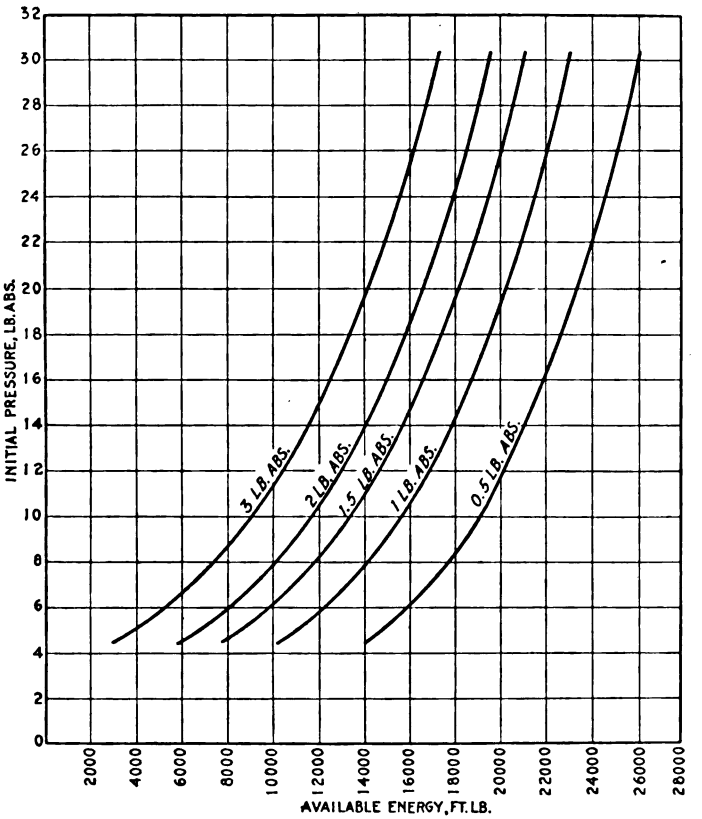


FIG. 2—ENERGY THEORETICALLY AVAILABLE FROM MERCURY VAPOR WITHIN VARIOUS PRESSURE RANGES

that it is very expensive, its cost being about 60 cents per lb. ($1.32 per kg.). Second, that it is poisonous and is capable of pervading the atmosphere in a very finely divided state in the neighborhood of places where the vapor can escape. Third, there are certain difficulties in confining both the vapor and the liquid, although these, with proper methods, are not serious.

Mercury's advantages as a thermodynamic fluid for the

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purpose desired are many. First: its boiling points at desired pressures are convenient. Second: its high specific gravity makes possible the use of gravity feed, sealing of valve stems, etc., and centrifugal sealing of turbine packings. Third: it is completely neutral, at the temperatures used, to air, water, iron, and such organic substances as it may come in contact with. Fourth: it carries nothing in solution which can adhere

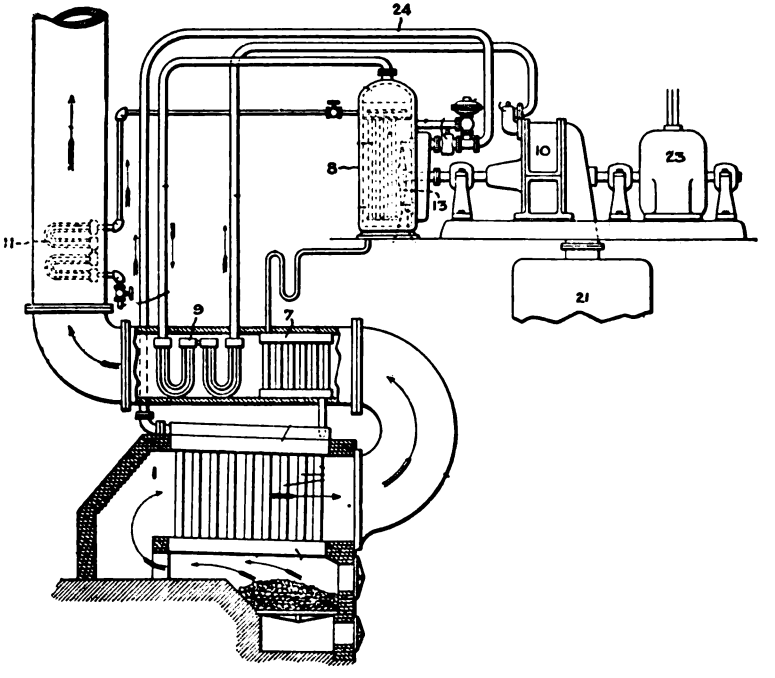


FIG. 3—DIAGRAMMATIC VIEW OF APPARATUS TO GENERATE POWER

1. Mercury vapor boiler.
7. Heater for liquid mercury.
8. Condenser boiler.
9. Superheater (steam).
10. Steam turbine.
11. Feed water economizer.
13. Mercury turbine.
21. Steam turbine condenser.
23. Electric generator.
24. Mercury vapor pipe.

to or affect heating surfaces, consequently the interior of boiler is always perfectly clean. Fifth: its vapor density is so high that it gives a very low spouting velocity, and consequently a very simple type of turbine can be used. Sixth: it does not wet the surface of turbine blades and consequently gives apparently no erosion. It is believed that the action between the vapor with its accompanying liquid and the blade surface will conduce to a high economy in a turbine, although no posi-

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tive data on this subject have yet been obtained. Seventh: Its volume at convenient condensing temperatures is such that it can be used in turbines without excessive bucket heights. One of the greatest limits of design in steam turbines is the large area required for the efficient discharge of the low-pressure steam. With mercury vapor, this difficulty does not exist. Eighth: delivering its heat at the temperature and in the manner which it does, the condensing boiler in which this heat is used to make steam is very small and simple as compared with a steam boiler. Steam boilers transmit an average of about 6 watts per sq. in. (6.45 sq. cm.) with an average temperature difference of about 1100 deg. fahr. A surface condenser transmits 18 watts per sq. in. with 20 deg. fahr. temperature difference. The mercury boiler is about equivalent in dimensions to a surface condenser, and since there is no high temperature involved, there will be no possibility of scaling or burning. Thus in this process we have low pressure and a clean boiler interior at the hot end, and small and perfectly distributed temperature differences at the low-temperature end of the process, where steam is made. High temperature, unequal distribution of heat, and the necessity for large heating surface constitute the principal difficulties of boiler construction. All of these are overcome in this method of making steam.

In this process the mercury vapor acts automatically as a conveyer of heat from the fire to the condensing steam boiler. If, through loss of load or other reasons, the mercury turbine admission is shut off, the vapor bypasses through a safety valve provided for the purpose, so that all the heat delivered to the mercury is immediately put into the steam boiler, except the fraction which is converted into power by the turbine.

Thus the fireman, in this process, will maintain steam pressure just as he now does. The steam produced will be used just as it now is in existing apparatus, and the output of the mercury turbines will be simply a by-product which is additional to the power which is now obtained. Studies have indicated that if this process works out as expected, the apparatus described can, in many cases, be put into the building space now occupied by steam boilers, so that the act of changing existing steam plants to this process should retain in use most of the existing investment.

Before entering into the details of experiments or of the methods by which it is hoped to accomplish these results, it may

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be well to state the degrees of economy which should be accomplished if this development succeeds. Assuming heat deliveries to surfaces exposed equal to those in steam boilers under equivalent conditions of temperature difference, gas velocity, and radiation, and assuming a turbine efficiency equal to that of steam under equivalent velocity conditions, the calculation shows that in an efficient modern power station, the same amount of steam can be delivered to the turbines at the same superheat, thus giving the same turbine output, and that in addition about 66 per cent of the power so delivered can be delivered by mercury turbines, the fuel required being only about 15 per cent greater than that which would be used with the steam alone. Thus the gain in capacity of an existing station would be approximately 66 per cent and the gain of output per pound of fuel would be about 44 per cent. This calculation is based upon a mercury vapor pressure 10 lb. (4.5 kg.) above the atmosphere and a vacuum of 28.5 in. (724 mm.) at the steam turbine outlet.

About 10 lb. (4.5 kg.) of mercury would be evaporated for each pound of steam produced, the steam pressure being about 175 lb. (80 kg.) gage, superheat 150 deg. fahr., and the final temperature after gas leaves economizer being about 300 deg. fahr. The vacuum in both steam and mercury turbines can be maintained by the same air pump, means being employed to separate all mercury vapor from the air in a suitable cooler.

A non-condensing steam plant produces more than half as much power from a pound of fuel as a good condensing station, and since the mercury process can be superimposed upon a non-condensing steam process as well as upon a condensing steam process, it is obvious that with the mercury combination the non-condensing plant can be made almost as economical as the best existing condensing plants. It is also obvious that when the mercury process is added in cases where steam is less economically used than in modern power stations, the gain will be relatively greater. The purpose of the process is to replace steam boilers wherever they are used and to obtain power from mercury turbines as a by-product.

Experimental data indicate that not more than $10 worth of liquid mercury per kilowatt output of mercury turbine will be required for such a process, and it is probable that with suitable arrangements, this amount can be considerably reduced. The general application of such a process would require im-

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mense quantities of mercury, but inquiry has indicated that the sources of supply are such that the largest conceivable demand for such a purpose would not permanently increase the price.

In the experimental calculations of this process which have so far been made, the vapor has been produced in heating elements similiar to those proposed for an actual boiler under the most severe condition of heat delivery by gas flow and radiation. The vapor has been carried from such boiler elements to a nozzle and this nozzle has been exhausted into a condenser from which the liquid is drained back into the boiler by gravity, the vacuum being maintained in the condenser by an air pump. In this experiment the only element lacking is the turbine wheel, which, although it constitutes the only visible evidence of results in such a process, is in reality unimportant, since the nozzle is the real engine which transforms heat into motion, the movement of the wheel by the moving fluid being a mechanical matter governed by laws which are very well understood.

In these experiments, pressures and amounts of liquid condensed were measured, and these measurements show that the flow of vapor through the nozzle was in agreement with the calculations from the data above stated.

In all the tests which have been made with these experimental elements, there has not been a trace of chemical action upon the mercury or steel, although air, water, oil, and various kinds of dirt have been present in considerable quantities, and although very extreme temperatures have at times been used.

Investigation of the conditions of heat transference and circulation in the production of mercury vapor has involved much labor in study and experimenting, and through this work certain data have been collected which, in combination with known data concerning action in different parts of steam boilers, have been applied to the design of a boiler of considerable size, which is now nearly completed. This boiler would appear to be the only part of the process which involves any difficulty, and it is hardly fair to expect that it will be in every respect satisfactory or in accordance with calculations, although the evidences in its favor seem to be very strong, and although every detail which enters into it has been the subject of successful experimenting. It is believed, however, that any difficulties which may arise can be corrected and that this process is prac-

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ticable for approximately such results as have been stated. A turbine of suitable design has also been produced, and a condensing boiler, with all the auxiliary apparatus necessary for the trial of the process as it might be applied commercially.

With a view to developing a design for a mercury boiler which would produce the vapor with the practicable methods of firing without destructive temperatures in the steel and with a small total amount of mercury in use, it has been necessary to do much experimenting to determine the behavior of mercury under boiler conditions. The first experiments made were with tubes containing solid cores with a small clearance between the core and the tube, and a central hole in the core provided for circulation of the liquid. The apparatus used in this experiment is shown by Fig. 4. A rod was carried downward through the central duct and projected out through a packing as shown. The relative expansion of this rod and of the outer walls of the tube was indicated by a multiplying lever as shown, which afforded an accurate measure of average temperature difference between the outer walls, which constitute the heating surface, and the liquid which was flowing in contact with the rod. This tube was subjected to various heating conditions and curves were plotted which compared rates of vapor flow with temperature difference. Some unexpected results were encountered, and the nature of the action was investigated by boiling mercury in concentric glass tubes having an annular clearance about equivalent to that used in the steel tubes. These experiments showed that to absorb a large amount of heat with a small temperature difference between the heated surface and the liquid, it was necessary to provide for a very free circulation of the liquid so that a large amount of liquid could flow. The size of the central hole had a very positive effect upon the vapor capacity of the tube. Since the mercury does not wet the heating surfaces, the tendency is for the vapor to fill the space between the liquid and the heating surface and thus to prevent heat removal. The way to get effective action in a mercury boiler is to create conditions by which so much liquid will circulate in hot parts that very little vapor is formed until the heated liquid reaches the upper parts of the tubes where the pressure is relieved, and where the heat stored begins to be released in vapor.

Difficulties with temperature differences are only encountered in the hottest parts of the boiler where radiation plays an im-

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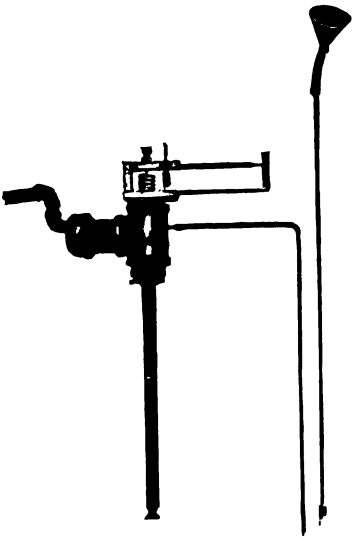

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FIG. 4
FIRST EXPERIMENTAL MERCURY BOILER TUBE

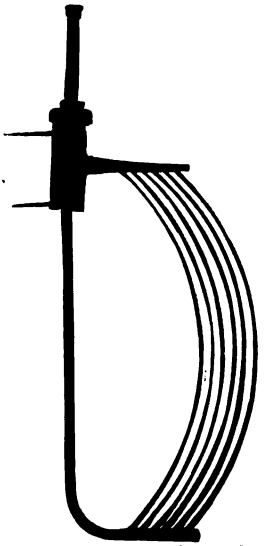

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FIG. 6
SECOND EXPERIMENTAL MERCURY BOILER TUBE

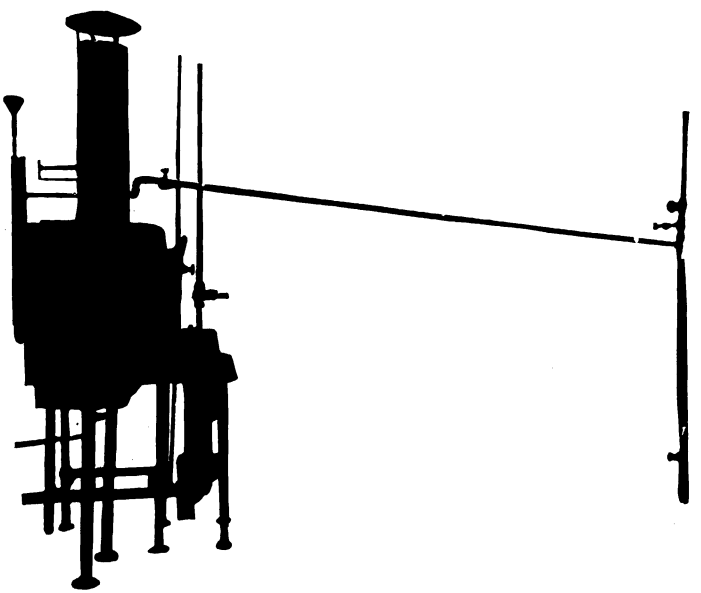

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FIG. 5—MERCURY BOILER TUBE OF FIG 4, ENCASED IN BRICK SETTING

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portant part. With the low rates of heat transference which prevail through a greater part of the surface, extremely narrow spaces can be provided for the circulation of liquid and for the release of the vapor which is formed.

Having obtained, by experiments, data concerning possible rates of heat transference, a boiler was built in which the heating surface was made up of round tubes with concentric cores. The tubes were expanded into a horizontal sheet which formed the bottom of a box, and arrangements were made by which the central ducts in cores always received a supply of liquid. The tubes in this boiler were rather thin, and in experimenting with it, it was found that at the hot end the expanded joints in the tube sheet became loose, the temperature differences imposing strains which exceeded the elastic limit of the metal. This trouble could have been corrected by acetylene-welding these joints, but this would have involved various changes and difficulties, and since trouble was also encountered in making the bolted joints of the box vacuum tight, it was decided to abandon this boiler and build another on an entirely different principle, which had been in the meantime devised and experimented with. The construction of this new boiler is shown by Fig. 7 and the experimental unit used to determine its characteristics is shown by Fig. 6.

This boiler is made up of a number of heating units, each consisting of an upper and a lower header which are connected together by curved flattened tubes. The flattening is to reduce the space which must be filled with liquid mercury without diminishing the surface. The curvature is to prevent mechanical strains through inequal expansion caused by irregular heating. These flattened tubes are connected into the headers by acetylene-welded joints. The tubes are first welded from the inside into channel-shaped pieces; these channels with the set of tubes connecting them are then annealed so as to release all strains incident to the welding. After annealing, they are tested with high-pressure air, suitable clamps being used to confine the air in the channels. If the welded sheets will stand the anneal and the subsequent pressure test, it is assumed that they will be reliable for service, since in service they will be subject to uniform temperature conditions and will be practically free from mechanical strains. These channel pieces are then welded to steel headers so that the whole unit becomes perfectly tight and capable of standing a high pressure. The

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headers of these units terminate, as shown, in taper nozzles, which fit into taper holes in the bus header at the bottom and into a vapor chest at the top. A curved liquid duct connects the vapor chest to the bottom header at the hot end so that

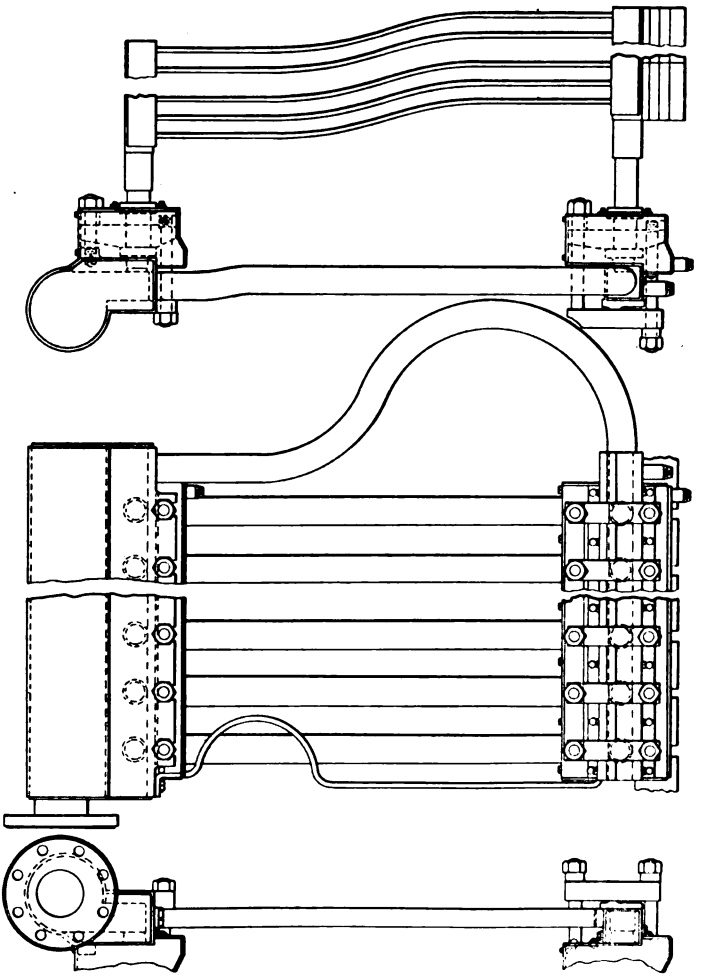

Fig. 7—Assembly of Experimental Mercury Boiler

the heating units which are exposed to the greatest heat receive the most direct supply of liquid. In these hot units, a larger internal space will be allowed than in the units which occupy the cold part of the boiler, so that the colder part will not carry an unnecessary amount of liquid.

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If these heating units will remain tight, and the success of experiments indicates that they will, it will be impossible for liquid mercury or vapor to escape except at the joints where

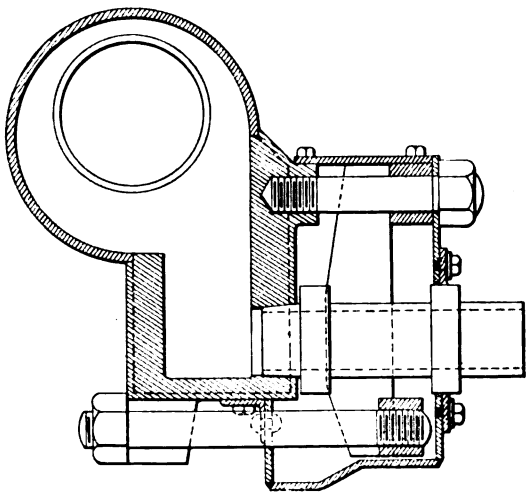

FIG. 8—SECTIONAL VIEW OF UPPER MAIN HEADER, MERCURY BOILER

these headers connect to the bus headers and to the vapor chest, or at the joints through which the vapor is conveyed to the turbine. To guard against loss through leakage in such places, arrangements have been made, as shown in Figs. 8 and 9, by

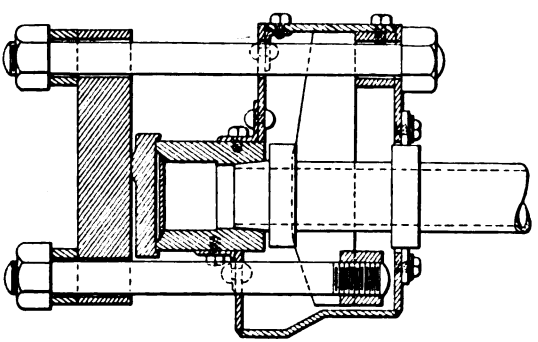

FIG. 9—SECTIONAL VIEW OF LOWER MAIN HEADER, MERCURY BOILER

which the sets of joints at the top and bottom of the boiler are enclosed in boxes which are practically air-tight, the bolts used in tightening these joints extending outside of the boxes in such a manner that a leaky joint can be drawn up. These boxes

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are connected by ducts to a condensing cooler in which low pressure is maintained by suction from the base of the stack or from any other sufficiently exhausted place. This suction will maintain within the boxes a pressure lower than any of

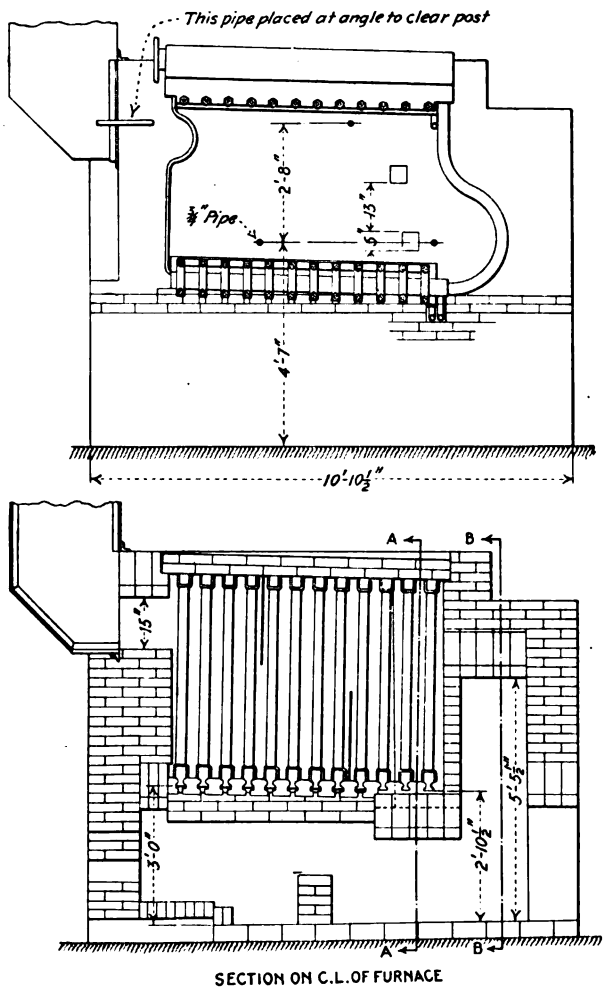


FIG. 10—MERCURY BOILER SETTING

the pressures which surround them, so that there will be a constant indraft of air through such leaks as may exist and a flow of all liquid or vapor which may escape, into the cooler, where it will be carried through passages over water pipes until all

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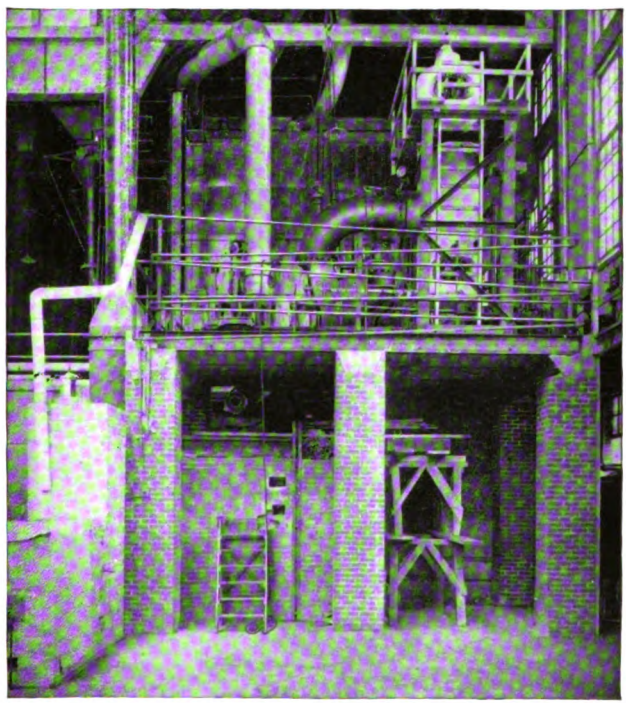

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FIG. 11—MERCURY BOILER AND TURBINE AS ERECTED IN POWER HOUSE

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the vapor is condensed and nothing but cool air and gas is discharged. In a similar manner, any joints in the system which might possibly be subject to leakage can be enclosed by boxes and connected to this same cooler. By this means, all possible leakage, except that which may occur in heating units, will be effectively caught.

In case there should be loss of mercury in any of the heating units, means are provided by which such loss can be quickly discovered before any large amount has escaped. The feed of each boiler is so arranged that it is governed automatically by the difference of pressure between the lower header from which

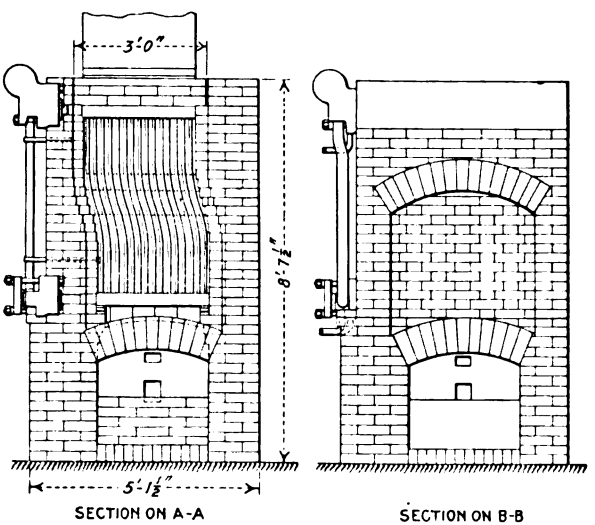


FIG. 10A—SECTIONS OF MERCURY BOILER SETTING SHOWN IN FIG. 10

liquid circulates and the pressure in vapor chest, this being the force necessary to produce sufficient circulation. Back of the valve which admits the feed, there is a reserve chamber, and connecting means are provided by which the level of liquid in this reserve chamber is visible to the fireman. In case loss of this liquid is apparent, the doors would be opened, the fire drawn, and the liquid drained out of the boiler into a receiving tank. The boiler can then be tested with air pressure and the leaky elements can be replaced, the construction being such that any one of these elements can be taken out without disturbing the others.

The arrangements of the turbine have also been improved as

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the result of experience. The first turbine arranged was made from an old experimental steam turbine and had many joints which were difficult to keep vacuum-tight. The new experimental turbine has only one joint, arranged in a manner which has been experimented with and which will avoid leakage.

The condensing boiler used in the experiment now in preparation is made from a standard high-pressure feed heater having a water space at the top and bottom connected by tubes in the manner customarily used in such devices. This boiler has apparently worked satisfactorily and produced steam from mercury vapor in the manner expected. It is not, however, considered a suitable design for the purpose, since the temperature differences impose a strain on the expanded tube sheets, It is thought that tubes attached at one end with concentric circulation after the manner of the Nicholaus boiler will afford the most satisfactory method for such condensers. Since no violent temperature differences will exist, it is believed that these condensing boilers can be made practically free from deterioration and entirely free from leakage.

As has been said, the turbine is provided with a centrifugal packing and is kept sealed by a constant admission of liquid mercury from a suitable level in the condensing boiler. The turbine is also provided with a throttle valve which can be used in governing, and with a bypass valve which allows the vapor to pass directly to the condensing boiler in case the admission to the turbine is shut off.

### Proposed Method of Commercial Application

The plan which has been considered for commercially applying this process is to produce a simple type of unit suitable for installation in the same floor space occupied by a standard 500-h.p. steam boiler. This unit would be so proportioned that the steam output of the condensing boiler would equal that obtainable from the standard 500-h.p. boiler. For each of these boiler units, a separate turbine and generator would be provided, the nature of this process being such that there is no loss of efficiency involved in such multiplication of generating units.

Since it would never be desirable to operate these mercury-driven generating units alone, the generators could be made either of the induction or synchronous type, completely enclosed, with an air supply from some clean outside source.

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Their circuits would run to the main switchboard, they would need no attendance, and the space around them would not have to be kept either cool or clean, although it would generally be possible to get them within an enclosure which would not be exposed to the fire-room dirt. By such means a single set of parts or combinations of a few standard parts could be made to cover a very wide demand, and this would greatly simplify the commercial introduction of such a process.

Without the acetylene welding process, a satisfactory mercury boiler design would be very much more difficult to arrive at. The manufacture of such boilers as are here described would involve a very large amount of acetylene welding, requiring great care and a considerable expense.

The possible cost of the commercial application of such a process has not been carefully studied. It has, however, been roughly estimated that if existing stations were converted to this method, the cost per kilowatt of added power would not exceed the present cost per kilowatt of well-designed steam stations, not including the cost of real estate. Thus this process, if successful, would greatly extend the capacity of existing stations and postpone the building of new stations, the saving would about cover the real estate values, and the gain in fuel economy over that of the best existing plants should be about 45 per cent.

Such a process, with the most efficient oil firing of boilers, ought to give a fuel economy very near to that which is commercially obtainable by Diesel engines, and its mechanical simplicity and freedom from the probability of deterioration should give it a very decided advantage over the Diesel engine. While it is not wise to make definite predictions about anything so radically new, it certainly appears to the writer that this process is worthy of very careful study.

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DISCUSSION ON GROUP II PAPERS (METHODS OF DETERMINING LOSSES IN APPARATUS), NEW YORK, FEBRUARY 27, 1913. (CONTINUED FROM NOVEMBER, 1913, PROCEEDINGS, PAGES 2007-2052).

(*Subject to final revision for the Transactions.*)

**H. F. T. Erben:** I wish to say a few words in relation to the possibility of obtaining a correction factor which will be universally applicable to machines of a given type.

I note in Messrs. Olin and Henderson's paper that they recommend certain correction factors, each of which will be applicable to all machines of a certain class. For example, they have a correction factor of 1.3 for direct-current generators and motors; 1.10 for alternating-current generators and synchronous motors; 1.10 for 60-cycle converters, and 1.0 for 25-cycle synchronous converters.

Our tests have shown that different correction factors must be applied to various types of machines comprising a general group, and these factors will vary very considerably. For example, we have shown that the correction factor for a fully compensated generator may be as low as 1.2 for a commutating pole generator about 1.3, and for a non-commutating pole generator it may be as high as 1.5. Again the correction factor for variable speed motors will be greater than for a constant speed motor, due to the distortion of the wave form.

There will also be a different correction factor for commutating pole and non-commutating pole synchronous converters and another correction factor for converters of the synchronous booster commutating pole type. It is therefore, evident that if we intend to apply correction factors we must subdivide any given class of apparatus into its various types in order that we may arrive at the true value of the efficiency. Such a course of procedure might lead to such a multiplicity of correction factors that the whole scheme would become unworkable. However, I am not saying this in any spirit of discouragement as I believe the various manufacturers should continue the tests which have been so ably carried out during the past few months and it might be advisable later on for the Institute to appoint a sub-committee to formulate rules based on all the available test data.

I fully believe that in those cases in which it is impossible to obtain accurate input-output tests that the efficiency should be determined by following the segregated loss method in combination with a suitable correction factor.

**B. A. Behrend:** All of us who have listened to the thoughtful remarks of Mr. Foster will, I think, be inclined to agree with him absolutely in his statements and recommendations. As I understand Mr. Foster, he desires to represent the full efficiency in his tests, and he suggested for alternating-current generators, of course, also for direct-current generators, the input-output test, which was first suggested in 1885, by the late Dr. John

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Hopkinson. The cost of that test is, however, frequently prohibitive. On that account it is difficult to carry it out in the power house or in the testing department. From time to time, however, two generators happen to be on the same shaft, either alternating-current generators, or direct-current generators, and then such tests can be made in a very simple and accurate manner, yielding very important data.

In applying these data to other cases, by using the experienced designer's judgment, we can obtain fairly good ideas of the actual efficiencies of machines, which can be used to form a basis for guarantees, even though, perhaps, we know only the individual losses. For example, if we have to guarantee a 25,000-kw. turbo generator, to operate at 1500-rev. per min., and we have the data on a 10,000-kw. unit, it would not be difficult for a man of Mr. Lamme's experience to make his estimates in such a manner that he would secure fairly accurate results.

The advantage of the use of the short-circuit loss curve, I think, is not to be underestimated. The use of one-third of the total loss is arbitrary and absurd, as Mr. Lamme justly pointed out. Whether or not we shall take the entire short circuit loss or whether we shall deduct from it the core loss, corresponding to the open circuit voltage, which corresponds to the short-circuit current, is a matter of judgment.

Mr. Erben's extremely interesting results have shown that in order to coordinate the data on different types of machines it will be necessary to use correction factors, "thousands of them," and we should be worse off at the end than we were at the beginning.

If we should deduct the iron losses from the short-circuit core losses, we would certainly get a more nearly accurate measure of the short-circuit losses than we should have if we included the obvious iron loss in the amount that we use for the correction. The philosophy, I believe, of this whole thing, comes right down to this—that the further our experience carries us, the more we doubt. Those of us who have been through the building of large machines up to 25,000 kw., at very high speeds, appreciate the fact that we continually learn. As Darwin said in the preface to his great work, "The Descent of Man," "It is more frequently ignorance that begets confidence than does knowledge." It will serve no good purpose to collect a number of utterly worthless correction factors. It is senseless to do it. You had better take the data Mr. Schuler mentioned today, calculate conventional efficiencies, and thus simplify your work. Conditions are constantly changing. You all remember that ten years ago the former Grand Central Station was completed. To-day that station has disappeared, and a new one, which has taken its place, has just been opened. Ten years ago the large 5000-kw. generators which Mr. Lamme designed for the Manhattan Railway in New York City were the leading machines of their class. To-day they are thinking of replacing them with turbo-

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generators. In ten years we have gone from 75 rev. at 5000 kw. to 1500 rev. at 25,000 kw.

I want to point out again that you are standardizing the past. Probably five years hence the facts will have ruthlessly wiped away the whole cobweb of rules we are laying down here. Your rules must be flexible, so that they can be applied to changing conditions. I plead for this because I feel very keenly the hampering influence of the old rules. It is a matter well worthy of serious consideration, especially by designing engineers. I know Mr. Lamme is in full accord with me. I do not like to say that for him, because he can say it for himself. I am sure I am in full accord with his ideas on the subject. It is extremely dangerous to go too far. The problem before us consists in laying down a few general rules which will not handicap and hamper the designing or consulting engineers. Make the rules general, and prescribe methods of test. For example, say whether the commutator should be seasoned at the factory or outside. If you do not want to say it should be seasoned at the factory; say it should be seasoned outside of the factory; if you do not want to say it should be seasoned outside of the factory, make such provision as you think is proper, but it is most important to do this, and to say what you want.

**W. J. Foster:** I want to say another word on the matter of the short-circuited core loss. I should hate very much to see correction factors adopted, one-quarter per cent, one-half per cent, or any per cent, that would punish good machines to the advantage of inferior machines. I should prefer to see the entire short-circuited core loss taken in order that we might proceed at once to reduce these losses. It can be done in nearly every case by better design, and that is what we all want.

The use of $\frac{1}{3}$ the short-circuit loss probably does not approximate the correct quantity that should be added. I think we should take the whole loss, and possibly a little more, rather than a little less. Mr. Behrend will excuse me for pointing out that, unfortunately, the other scheme to which he referred would result in boosting the efficiency of two-thirds of the commercial machines at the present time, for the reason that the excitation that is required to put the short-circuit current through, gives an open circuit, a higher core loss than the entire short-circuited loss on most machines and, therefore, when you subtract it, you get a negative value, and if you add that negative value to the other losses, you will have your efficiency raised rather than reduced.

**B. A. Behrend:** I meant to correct the exciting current for the armature reaction. I did not want to go into that detail.

**W. J. Foster:** Just the reactive drop?

**B. A. Behrend:** Simply take the reactive drop. I took it for granted that should be taken into consideration.

**W. J. Foster:** In line with Mr. Lamme's suggestion of correcting the core loss, or the combined loss and $I^2R$, I have

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never succeeded in getting anything that was reasonable or that fitted the case; I trust that some positive evidence will be brought forward that the entire short-circuited core loss is the wrong thing to take. We will probably have to wait until some one has a pair of identical machines to test by the " circulating energy " method, which we appear to agree on, and on those same machines have the short-circuited test applied, and find the case where the correction as determined by the short-circuited loss is going to appear absurd when compared with the actual stray load loss, and then we will have some direct evidence.

As stated before, I regret that the particular machines that were available for use in connection with paper No. 23 all proved to have small short-circuited losses, as polyphase machines, but does it not seem significant that one of these has very large short-circuit losses as a single-phase machine, and that these losses agree very closely with the load losses as determined? There have been a number of cases in the past with which I have had to do, of single-phase machines, where changes were made after the first tests, in order to reduce temperatures, in connection with which the short-circuit losses were reduced.

Therefore, I consider that the evidence presented by the curves Figs. 9, 10 and 11, of the paper by Foster and Knowlton, should be taken up and carefully considered by the Standards Committee, and something in the way of positive evidence to condemn them should be obtained before they are rejected entirely.

**James Burke:** The papers under discussion and the corrective factors introduced should not, perhaps, apply only to the machines, but also to the instruments and to the men, and I think that these tests show that instrument designing is in the same high class as dynamo and motor designing, they show such close agreement with what might be expected from dynamo and motor tests.

It seems to me that the function of the Standards Committee is to standardize and not to average. The suggestions throughout these papers for corrective factors is to average these factors, and that eliminates the individuality of the designing. Now, it is quite possible, and I think most designers will agree on this point, to have negative corrective factors. For example, if we take a direct-current generator and so shape the pole pieces with varying air-gap so that the distribution of flux is approximately a sine wave under load, which would be quite different free, then our load core losses are less than our free core losses. That is not only a theory, but I have proved that by tests. I know that some European machines have been built that way, in which the air-gap is so proportioned that the influence of the armature reaction is such as to produce very nearly a sine wave under load. Now, if a designer introduces such a feature as that, that is a negative corrective factor, he gets no credit for it, and his individuality is removed as soon as the Standards Committee averages these factors. The question of compensated machines,

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the difference between the 60 per cent compensated machine, which Mr. Erben has referred to, and the 100 per cent compensated machine, would have to be taken into consideration by the Standards Committee, or the punishment due to the average law would apply. In the compensated machine we may have large corrective factors, depending on the distribution of the compensating conductors. If you have two or three compensating conductors per pole, you probably will have quite a different increase in loss under load than if you have a larger number.

To do any good, to get any reasonable consideration for corrective factors, the Standards Committee would have to tabulate on the alternating-current end of motor-generators a great many construction details, whether the slots are closed, or open, or partly closed, the depth of conductors, many factors of that kind, to determine the corrective factors or the alternating-current end, and similar treatment on the direct-current end. Then you would have to introduce factors covering the way that the brush losses were determined—I think we have heard this afternoon that there are a good many different theories on brush losses and different opinions as to the amount of brush losses. Now when it is all finished, all that we have accomplished is the recognition that there may be, and it is to be expected that there will be, some corrective factors on account of loads, but I do not think we have any idea as to how much they should be. Personally I have conducted a number of tests in which I have found so little corrective factor that I could not say I had found any, and in every case there has been a large difference. I am making a plea to avoid the averaging of these corrective factors and leave some room for individual effort in telling the story of the individuality of different types of machines.

**Charles P. Steinmetz:** I can see a nice time ahead for Mr. Lamme and myself as members of the Sub-Committee on Revision when we attempt to designate the exact methods of determining the stray load losses so as to give the operating engineer the exact and true efficiency which he wishes to have, and which the input-output method, as I understand, is incapable of supplying, and which you cannot get by considering the short circuited core loss, or open circuited core loss, or any other thing, except by using correction factors, and as many different correction factors as you build machines. Our only hope is that we shall be assisted by the engineers who are now interested in the stray losses, by constructive criticism, that is, when we have drafted a tentative rule we shall submit it to them, and in case of their disagreeing with us in our first attempt, we hope they will send us back material for the formulation of a better rule.

In regard to the short circuit core loss, as shown in the diagram which Mr. Behrend discussed, I wish to say that ½ of the short circuit core loss was not a mere incident, and while at present the data seem to show that the total short-circuit loss is more

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correct, we must realize that when the rule was made we had different machines to deal with. The single-phase slow speed alternator was a very common machine then, also other types of machines which we rarely see now, such as the inductor alternator, where the field exciting winding was far away from the armature, separated by solid magnetic material. In these machines the pulsation of single-phase armature reaction reached back throughout he entire field when you ran at the low densities corresponding to the short circuited core loss; while at the rated voltage, especially in a highly saturated machine such as the inductor alternator, the pulsation due to the single-phase armature reaction is very much less, and we knew, if we used the full short circuit core loss, there could not be a loss of any such magnitude because the machine would have burnt out in less than no time, and therefore, especially since people were rather horrified when we made the first test of that character, and found these apparently enormous losses, we had to play safe and use a value which we knew was less than the probable true value. However we were proceeding in the right direction to the extent that instead of neglecting the short-circuit loss altogether, we at least took in a part of it.

Now, the short circuit loss undoubtedly gives some indication. The residual loss after deducting the armature $I^2R$ loss and the iron loss corresponding to the approximate magnetic density under short circuit tests, affords an excellent criterion as to the extent of the stray losses at full load. Even if in some cases it leads to ascribing to the machine an efficiency lower than is actually obtained nevertheless the general adoption of the plan of taking this residual short circuit loss as a measure of the stray loss at full load, would provide designers with a criterion which would lead to designs of improved quality.

**E. M. Olin:** Although Mr. Robinson, in drawing his conclusions, in his paper, states that the input-output method of measuring efficiency is "one that can be considered only in connection with special investigations" and "as a check method for demonstrating the reliability of other methods better suited to commercial needs," it is a fact I think that a reading of this paper would lead the average engineer, inexperienced in this class of work, to believe that this method is perfectly simple and thoroughly reliable for measuring the efficiency of rotating electric machines. Such a conclusion is so at variance with the experiences of the writer and a number of engineers with whom he has been associated, extending over a number of years, that it seems advisable to point out a few contributing factors not taken into account by Mr. Robinson.

In propounding the mathematical theory which deals with "indeterminate errors" and the average deviation of the mean reading from the true value, for the purpose of illustration, use is often made of an example like the following: A skilled marksman fires a thousand shots at a target under conditions

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as nearly alike as possible. Experience shows that the shots will be distributed in a manner which at first sight seems entirely irregular but which, on more careful examination, will be found to be approximately in conformity with a perfectly definite law, the law of chance. The plus and minus deviations of the shots from lines drawn at right angles through the center of the target are about equally frequent, and small deviations occur with much greater frequency than large ones.

It can be shown mathematically that there is a certain definite curve, representing the law of chance, whose equation can be expressed in symbols, and that the average deviation of the mean is as shown by Mr. Robinson.

Now, in this example of the marksman firing at a target which I have just cited, it should be borne in mind that the target is fixed, not swinging.

In input-output tests the mark at which we are firing is the true value of efficiency. However, the true value of efficiency is the ratio of the output as determined from measuring instruments in the output side to the input as determined from certain other measuring instruments in the input side. In other words, during our observations we have two targets and two marskmen or sets of marksmen.

Now if the output is constant for all readings, the target remains fixed, and it would be correct to figure the input and output separately according to Mr. Robinson's method but not the efficiency direct from each observation or set of observations.

In the tests described, however, the output is not constant. In Table II, the output ranges from 470 kw. to 512 kw., a variation of some 40 kw. The target at which the marksmen are firing then, instead of being fixed, is swinging.

Now the instruments used in the incoming circuits of motor generators, such as are covered by Mr. Robinson in this data, do not swing synchronously with those in the out-going circuits due to the different types of damping used in the various instruments, the introduction of series transformers, etc. This introduces another complication in figuring tests such as described in this paper. The target which should be fixed is not only swinging, but swinging along an irregular curve with a varying time constant. Obviously, the problem is not quite so simple as one might be led to believe from glancing over this paper. It is undoubtedly true, as stated by Mr. Robinson, that certain of the no-load losses may change during the progress of the input-output tests. These should be measured carefully by the separate loss method and due allowance made when computing efficiency for such changes and average values should be used for such factors as frictional losses in brushes and bearings and brush contact losses.

**L. T. Robinson:** I am willing to admit the extreme difficulty of satisfactory input-output testing but not its impossibility. Mr. Newbury said that the test results obtained were not right

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because they departed from well-known laws. We have been all day yesterday and today discussing these well-known laws and there appears to be no definite understanding of them on which definite criticism of the results obtained could be based.

With regard to the shooting at the swinging target, I cannot see that this has any bearing, as long as the individual observations of the output are not far enough apart, so that the efficiency line that joins them does not depart substantially from a straight line. I do not recommend these methods for practical tests. I think that an impartial examination of the evidence presented will indicate that the results are correct within the limits stated. If you cannot look at it that with the input-output test we prove that the circulating loss tests are right, perhaps you will look at it the other way, and say that the circulating loss tests prove the input-output tests are right, because we got the same answer by both methods. After a full appreciation of the variability of the brush friction, etc., came to my notice, we made some more tests, and every point comes within the degree of the precision claimed, and beyond which I did not care to go.

As to the No. 3 test in the paper, I think I made it quite clear that that was not very good, and I think the reasons given were quite sufficient. In a machine in which the brush friction is about one to 1.5 per cent of the total output, and with the statements this afternoon, by presumably competent observers, that brush friction varies 300 per cent, why is it any fault of the method or the test if the points do not fall all within the belt? I submit that the evidence is sufficient to establish all the claims made.

**C. J. Fechheimer:** In the paper by Messrs. Foster and Knowlton on the last page they state "The phase characteristic method is faulty, due to the difficulty of obtaining accurate wattmeter readings at the low power factors." If we have a three phase circuit and use single phase wattmeters and the power factor is less than 20 per cent both wattmeters will indicate high values, although one wattmeter will read negative. The true power is the difference between the two wattmeter readings. Both wattmeters read with considerable acccuracy and the only inherent errors which are introduced are those due to observation and the difficulty in obtaining with accuracy the difference between two nearly equal quantities. However, the error that we usually think of in connection with single phase wattmeters when connected to low power factor circuits does not apply to the three phase case with the standard two single phase wattmeter method, because a single phase wattmeter reads inaccurately when the current and electromotive force are nearly in quadrature and this condition obtains when the power factor of the three phase circuit is not far from 50 per cent.

It is our opinion that the phase characteristic method is the most accurate one for measuring the losses within the machine,

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with possibly the exception of the circulating energy method. This latter, however, can be used so seldom that we must resort to some other means, and usually the phase characteristic method can more frequently be employed with equipments in most test departments in manufacturing companies.

In regard to the modified segregated loss method, we believe that all of the short circuit losses should be included instead of one-third of the short circuit losses and that the core loss should be taken at the internal voltage as given by the terminal voltage plus the impedance drop taken in the proper phase relations. The reactance of the armature winding may be measured with the rotor removed, the current being circulated at normal frequency in only one of the phases. The reactance thus determined may then be used for computing the internal voltage.

**B. A. Behrend:** In the papers that are before us the difficulty of measuring the power in watts or kilowatts has never been discussed. This is rather surprising. Mr. Robinson will appreciate the immense difficulty of obtaining correct wattmeter readings. I remember in the early days it used to be one of the most difficult problems, and the new instruments have by no means solved it. Even the best instruments for the purpose are influenced by the proximity of large currents circulating in cables and by magnetic fields which exist almost everywhere in the shops. Let us take a simple case, and endeavor to determine the power factor of an induction motor at different loads. I have had experience in that direction, and I have had working with me some of the learned professors of our great universities, and have found it necessary to correct power factors of 101 and 102 per cent., to harmonize them with reasonable facts. It is so important a matter that I believe it should not be omitted in our consideration of this complex subject.

I want to say that in a number of cases of high tension circuits, I have found that the power factor of an induction motor was extremely low due to the peculiar condenser effects in the shunt windings of the wattmeters. It is an effect which it is very hard to eliminate and very hard to correct. At low power factors this effect is tremendous. Of course, it can be corrected in the well-known academic way, if we care to pile assumption on assumption. This is a matter of importance. Mr. Robinson might give us his views of the accuracy of wattmeters and their use in alternating-current circuits in power houses and on the testing floor. I have personally no faith in them, and I am just as willing to take the no-load current of the induction motor and use the simple circle diagram developed by me in 1896. When stimulated by the difficulty of harmonizing the results of wattmeter measurements with the likely facts,in order to get an idea of the power factor.

**L. T. Robinson:** You may be interested in my views on what accuracy we can obtain with wattmeters in commercial testing. First we will take the wattmeter as it is, and then we will see how much influence the testing floor has on it. We can build

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wattmeters, and they are constructed and obtainable commercially, that will measure with power factors down to 10 per cent, within about 2 per cent of the correct value. That 2 per cent is largely correctable. This refers, of course, to single-phase operation. But you can, I think, get the best results when you want a really close measurement on three-phase circuits at low power factor, by using three instruments, so that you do not have the trouble that you have in subtracting one reading from another, which, of course, when they are pretty near alike, is bound to introduce large errors. You can choose instruments that will go over the scale, perhaps with one-third of the product of the rated volts and amperes of the circuits, and use three, and get very good results. When you introduce larger quantities for volts and amperes you must, of necessity, employ instrument transformers. Now, the phase angle between the secondary current and the primary current in the current transformers is determined within, perhaps, three to five minutes of the equivalent angle, which again brings you substantially within the limits spoken of for the wattmeter alone. The total magnitude of that phase difference can be kept small enough so that correction is reliable.

With regard to the potential transformer, it is possible, practically in ordinary work to eliminate them altogether, because the usual transformer is so constructed that with non-inductive load at certain loads the phase displacement between primary and secondary voltages is zero, and you have only to find out what that load is and put it on in addition to the wattmeter potential coil to bring the angle to zero, and use it that way. How far that can be applied to the testing floor, I do not know. You have things to deal with there that are difficult to handle. The difficulty is not great if you can retain the people permanently who have been shown how to do the work. I will admit the trouble in doing such work commercially, but when the real necessity for it arises, I do not think the instruments or the method will be found wanting.

**B. A. Behrend:** The disturbing effect in the neighborhood of the wattmeter is because the wattmeter is so apt to be influenced.

**L. T. Robinson:** I feel sure that the instruments to which I refer are entirely free from those disturbing effects.

**Carl J. Fechheimer:** I always understood that the wattmeter was incorrect, and the current in the measured coil is almost in quadrature with the current in the corresponding coil.

That only occurs at 50 per cent power factor, or approximately 50 per cent power factor.

**L. T. Robinson:** It does not occur at 50 per cent power factor when you use three instruments. The power factor on each instrument is the power factor of the whole circuit.

**Carl J. Fechheimer:** Will you have correct results on your two instruments when one wattmeter reads a negative value and the other reads a positive value?

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**L. T. Robinson:** Incorrect. In comparison with the results obtained with three instruments.

**Carl J. Fechheimer:** Why?

**L. T. Robinson:** You are substracting one thing from another thing, to which it is very nearly equal, and a very small inaccuracy in the wattmeter becomes a large part of the difference which is shown.

**Carl J. Fechheimer:** Each wattmeter will read fairly correctly?

**L. T. Robinson:** Yes.

**C. A. Adams:** I will answer one part of Mr. Fechheimer's question. In the case of the two wattmeters three-phase power measurement with nearly 50 per cent power factor, where one wattmeter reads zero, or very nearly zero, the per cent error of the low reading wattmeter may be very large but the actual numerical error of the total measurement is exceedingly small, and quite as small as when both wattmetters read high.

**James Burke:** If I may be permitted to make a suggestion to the Standards Committee, it is that in preparing new rules, they should not overlook the introduction of the necessary rules for the correction of instruments when efficiency tests are made by input-output methods. We have heard quite a little on that this evening, and I think it is very important, since input-output methods do come up occasionally, that the Standards Committee tell us how to introduce corrections on wattmeters and on various other instruments that come into use, and also to correct for the nature of the voltage supplied, whether pure sine wave or a wave that has some other complications in it. I think that is going to be quite important, because otherwise input-output methods will be relied upon, without their proper correction factors, and it may be that the correction factors for input-output methods would be as large as on the summation of loss methods, and that it is equally important not to overlook them.

**B. A. Behrend:** Mr. Burke's remarks should be endorsed emphatically and heartily by all of us. We must know how to correct instruments. I have never been able to get accurate readings in a testing department because of the effect of large magnetic fields around the instrument. You cannot shut down a large manufacturing plant, employing twenty thousand men, for the sake of making one test. Night testing and Sunday testing are equally unsatisfactory for other reasons. I want to know if wattmeters can be obtained commercially which are not readily influenced by outside currents and powerful magnetic fields.

**L. T. Robinson:** Yes.

**J. L. Harper:** We have heard a great deal of discussion as to corrective factors, and my remarks this afternoon, have been referred to by Mr. Newbury as not being pertinent to the discussion, but as I understand it, the necessity for determining all these losses is for the purpose of arriving at efficiency. I do

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not wish to have it considered that any remarks of mine had reference to any special method of test, or to any test, I merely desired to protect true efficiency from the corruption of a commercial understanding of efficiency; and instead of applying so many corrective factors to the losses, why not apply one corrective factor to the efficiency?

Mr. Schüler spoke of using the word "conventional" efficiency over there, why not use "conventional" or "commercial" efficiency for what manufacturers are able to determine as efficiency. You all seem to agree that you can determine certain of these losses with fair accuracy. Why not decide upon these losses and set them apart and let them be determined, and call that a certain kind of efficiency, designate it by some kind of qualifying term that will differentiate it from the true efficiency, and eliminate the necessity for the use of these thousands of corrective factors. That also may assist Dr. Steinmetz in solving that very difficult problem of satisfying the operating engineer in getting the true efficiency, which you all seem to claim is a physical impossibility. That may be so at the present time, but as time goes on the distance that separates the losses that you are able to determine by the segregated loss method from all losses, I think will decrease, and there will come a time when further characteristic losses will be added to the determinable ones, and the difference between true efficiency and "commercial" or "conventional" efficiency may be decreased. The present rules I believe to be inconsistent, in that they give a fairly clear definition of efficiency, and then say that efficiency may be determined by the measurement of the losses separately. You have made it very clear to me that it is a physical impossibility to determine these losses separately. Therefore, this efficiency which the rule purports to approve, is not a true efficiency, but some qualifying efficiency which you may call "conventional" or "commercial."

I merely wish to make the suggestion that by incorporating this one corrective factor, (which may be $\pm X$) in the efficiency you make unnecessary all of these thousands of other corrective factors, and thus simplify both the matters before you in discussing the losses, and also the work of the Standards Committee in endeavoring to satisfy all parties.

**E. I. Chute:** It is very true, as Mr. Behrend and Mr. Robbins brought out, if we try to make constants to account for the additional load losses for all types and sizes of apparatus we will have constants as numerous as the sands of the sea. But the case is not as bad as that. There are not very many operating or consulting engineers complaining about the smaller types of apparatus; it is the larger types, where one per cent in efficiency counts in dollars and cents. In these the constants can be simmered down to comparatively few in number as will be noted in the summary to the paper by Messrs. Olin and Henderson. It must not be thought that these constants are absolute, nor do they need to be. No method of test now in use

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even with the help of the laws of chance and Mr. Robinson's shaded belt will assure us of the true efficiency of a machine within two or three tenths of one per cent. The additional load loss, being small in proportion to the total losses of any machine may vary materially, often even 25 to 50 per cent without affecting the actual efficiency more than a quarter of one per cent so even though the additional load losses may vary slightly in the various types of the larger machines, a large number of them may be bunched together under one classification. An average constant for such a classification, applied as suggested, will then give operating efficiencies as accurate as the average engineer demands.

The average input-output test is not acceptable to either the manufacturer or operator and some other solution of the problem of determining true efficiencies within reasonable limits must be worked out. The sooner we make a start at it the better.

Mr. Robinson's paper serves to bring out very nicely the limitations of the input-output test even when taken under the best conditions and the calculations made with all the refinements of mathematics. On curve 1 in the discussion by Mr. Collins, two values of efficiency are given at normal load, the difference apparently being due to the exchanging of one instrument for another of similar capacity and accuracy. It will be noted that there is a difference between these values of four tenths of one per cent, a greater difference than accounted for in either test by any possible change in constant losses. Why might not this discrepancy have been in just the opposite direction to that shown?

The values of additional load loss obtained in all the tables but IX, X and XI speak for themselves. If these values are correct, why all this agitation? The separate loss method of efficiency determination is good enough. If such results with the input-output method of test are obtained by Messrs. Robinson and Collins with their reputation for refinement and accuracy, what can the rest of us hope for?

**L. T. Robinson:** There should be no misunderstanding on that point. The only claim I make is that these points will fall within that belt. And they do. The instruments were interchanged, at one point, and there is no conclusion to be drawn from the result except that the results are within one-quarter of one per cent because the belt is only that wide and the points fell within the belt.

**E. I. Chute:** Other unaccounted for inconsistencies in these tests might be pointed out and it is my personal opinion that an accuracy of two tenths per cent claimed for them is not warranted. It only goes to show that even when the most elaborate and refined of methods are applied to the input-output tests the results are very uncertain.

**H. M. Hobart:** No mention has yet been made of the best method of determining the true efficiency, the method which

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the Standards Committee would probably be well advised to adopt, and that is a method based on calorimetry. For instance, one can measure the losses at no-load with exactness, while a given quantity of air is being passed through the machine. The temperature of the air at the inlet and at the outlet can be taken. Again the machine can be run at full load and the same quantity of air measured at the inlet and outlet. This gives a simple way of deducing quite exactly the ratio of the losses at full load to the losses at no-load, and consequently of arriving at the magnitude of these stray losses and consequently also of deducing the true efficiency. I believe that by these means we may arrive much more closely at the true efficiency than by any other practical method.

I allude first to large machines, because generally the conditions surrounding the contract for large machines are the more important, but in my opinion for smaller machines calorimetry also offers the best method. In the case of a small machine, you can house it completely. You can house the motor in a case, through which you pump air, measuring the quantity of air, its inlet temperature and its outlet temperature. The measurement is made first with load. Then the measurement can be repeated at no load with the addition of suitably disposed rheostats, into which you can introduce an additional loss, which will give you the same inlet and outlet temperature when your machine is running unloaded as was obtained in the first test when running it at its rated load. The amount of the losses in these rheostats will be equal to the load losses, including therein the legitimate and the illegitimate load losses.

Another way is to have your machine in one receptacle and then let the air pass on to still another receptacle in which you have your rheostat, and get the temperature drop across each. It is a thermal-drop process. When the thermal drop across each receptacle is equal, then you know that the loss in the machine is equal to the loss in the rheostat. If the drop is not equal, you can get the loss by taking the ratio of the thermal drops. There is no need to measure the *quantity* of air but merely to maintain the flow constant.

**W. F. Dawson:** The method proposed by Mr. Hobart is interesting and replete with possibilities, but it requires much study and care so that new sources of error are not introduced greater than those contended with previously. The difficulties of successfully measuring the actual amount of air delivered, and charting it so as to get a true average, are very great. I have been recently checking up losses with the thermal capacity of the air passing. There is probably additional loss, by heat convection, that will not be measured by thermal capacity of the air passing through. In respect to turbo-alternators, and particularly those which are provided with definite air passages for inlet and outlet, it will be exceedingly instructive to make these tests and keep them for comparison and reference. I doubt very much if the consulting engineers and the customer will

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very rapidly embrace the facilities which Mr. Hobart has offered in respect to determining these load losses. Mr. Erben has shown splendidly how these load losses are affected by design. It would be a great mistake and an injustice for the committee to lay down any set of rules and say that " this class of machine shall be considered to have $\frac{1}{4}$ of 1 per cent additional loss " and " this class of machine shall be considered to have $\frac{1}{2}$ of 1 per cent additional loss," etc., because it will handicap individual initiative. It will put the designer and the manufacturer of inferior machinery, to a certain extent, on the same basis as the designers and manufacturers of machines who have practically eliminated these load losses. I hope the discussions and investigations will go on. There cannot be any question but that this discussion will make for better designs of machines, smaller load losses, or a considerable elimination of them. Mr. Lamme pointed out, and Mr. Erben and Mr. Burke, and others, have also pointed out, that while we may indicate what these losses are, it is going to be an exceedingly difficult thing to standardize them.

**H. M. Hobart:** I do not propose to measure the quantity of air. That is difficult. We do not measure the quantity of current when we get the drop through two resistances. We keep the current constant. The air flow is kept constant by running the fan or blower at constant speed. There is nothing new in calorimetric methods.

**B. G. Lamme:** I have listened with a great deal of interest to what Mr. Harper has had to say on the question of load losses. He says that if we cannot measure all the losses, and will state what we can measure, and if we are willing to state the situation plainly, he is willing to accept it. If everybody else would agree with him in this, it would make it very easy for the Revision Committee. Mr. Harper called attention to putting a factor $x$ in the equation. However, it has been suggested by others that such a correction factor puts a penalty on good design. That is true, but you must not forget that virtue is its own reward. The designer who builds with very small extra losses has a correspondingly better machine, because any reduction in such losses reduces the temperature, and therefore allows him to correspondingly increase the output. The designer who builds with high extra losses will eventually lose out, so that the normal tendency is toward the reduction of such extra losses.

Mr. Harper also stated that eventually we would come closer to the true efficiency. I agree with him, but possibly it will not be so much by improved means of measuring as by reduction in the extra losses. I know that, right now, the tendency toward reduction of the extra losses is very strong, and that all losses in the machines are being analyzed and studied very carefully with a view to getting better performance and larger outputs by eliminating all unnecessary or useless conditions.

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DISCUSSION ON "OPERATION OF TRANSMISSION LINES" (HAGOOD), SAN FRANCISCO, CAL., FEBRUARY 28, 1913. (SEE PROCEEDINGS FOR DECEMBER, 1913.)

(*Subject to final revision for the Transactions.*)

**Herbert W. Crozier**: We are certainly much indebted to Mr. Hagood for the interesting paper we have had tonight, particularly the slides, which show great care in preparation.

I wish to ask him a question. With regard to the use of synchronous condensers, what do you find is the most satisfactory method? Suppose you have a large amount of power to deliver to consumers which would involve the use of synchronous motors driving direct-current generators,—would you prefer to make those synchronous motors just large enough to carry the load and have an additional machine synchronous to the condenser, or would you prefer to make the synchronous condensers large enough to take care of this regulation? That is the first question, and then the other is, what would you do if you had synchronous converters? That would be a different phase of the same subject.

**Lee Hagood**: With the synchronous machine, whether it is a generator or a motor, it can effect power factor correction and at the same time do work. I did not dwell very much on that point, because so many think that is the only way, economically, to use synchronous machinery for power factor correction. The ideal way of course is to let the synchronous machines do 70 per cent in kilowatts and about 70 per cent in wattless kilovolt-amperes, that is, rate these machines on a 70 per cent power factor basis. This applies to synchronous generators, frequency-changer sets, and synchronous motors. It is not always practical to locate these machines at the points where power factor correction is desired, hence the necessity for synchronous condensers.

The characteristics of a synchronous converter are such that its design does not lend itself to operation other than at 1.00 power factor at full load. It would not be safe, in general, to give operators instructions relative to using synchronous converters for power factor correction on light kilowatt loads, as a departure might lead to damage to the machine.

**Herbert W. Crozier:** Then I gather from your statement that the synchronous converter is fixed by the direct-current voltage, so any small amount of voltage control available would be fixed by the direct-current voltage, which presumably you would desire to keep constant.

**Lee Hagood:** That is one of the difficulties.

**Herbert W. Crozier:** But in regard to motor-generators driven by synchronous motors, if we take, for instance, a unit which would have a 1000-kw. direct-current machine, then the idea would be to purchase the motors considerably larger?

**Lee Hagood:** Yes.

**Herbert W. Crozier**: So as to take 70 per cent. You make the motor part 30 per cent greater?

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**Lee Hagood:** Yes. It is not a good thing, in all cases, to put a voltage regulator on the motor, unless it is relatively large for its purpose. Even then the voltage regulator must be restricted in its operation so that no danger is incurred of the machine falling out of step by attempting to take a heavy kilowatt load on a weak field.

**Robert Sibley:** I notice that it has been announced that the Chicago, Milwaukee and St. Paul Railway will electrify some 500 miles (805 km.) of its line through Montana, and the proposal is to purchase power from the Great Falls Power Company at half a cent per kilowatt, the company agreeing to wholesale the power from the main transmission line. However, the power company also reserves the right to put in regulating devices at the receiving end. I would like to ask Mr. Hagood how such devices would differ in railroad work from such installations as he has shown us this evening.

**Lee Hagood:** As long as they are motor-generator sets it would be quite feasible to accomplish automatic voltage regulation provided the conditions were such that the machines would not have to run on weak fields, but if they are converters, I do not see how it would be practical.

Sometimes motor-generator sets are operated with fixed field excitation, or it is compounded so that as the load comes on the excitation is increased.

**Herbert W. Crozier:** One example of this phase control, that has worked out very successfully on the coast, is the Sierra and San Francisco Power Company, delivering power to the United Railroads. On their transmission line, 135 miles (217 km.) long, the same voltage is obtained at both ends of the line. The motor-generators are all 1500 kilowatts, I believe, and the regulation is obtained by controlling their fields. I believe they have now installed voltage regulators at a number of the stations and are getting very satisfactory voltage. This condition of course is one that does not always occur in regular commercial practise, because the power company has full control of a very large amount of synchronous apparatus at the receiving end. The ordinary condition is where there are many consumers taking current and using it any way they please, and it is up to the power company to make such regulation as it is able to. In such cases the synchronous condensers discussed tonight are apparently a very excellent feature. One thing that impressed me greatly was the fact that by the introduction of a synchronous condenser results are obtained amounting to 25 to 30 per cent additional power delivered over the transmission lines, which certainly would appeal to our commercial friends as a considerable saving in capital expenditures necessary for transmission lines or for additional machinery. Heretofore we have been forced to buy generators to take care of the wattless current—and then more generators; and the use of the synchronous condenser in the substation is certainly a very valuable feature.

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One thing that impressed me more than any other was the curve shown, if I remember the figures correctly, where 25 per cent more power could be delivered over the same transmission line with practically the same regulation.

**A Member:** Under what conditions, if any, is the use of synchronous condensers warranted by the decreased power loss due to the necessity for transmitting less wattless current through the line, apart from the question of voltage regulation? Another question. Is it possible to build synchronous condensers simply for regulating purposes so that for a given kv-a. capacity they are cheaper than a synchronous motor of the same capacity would be?

**Lee Hagood:** In regard to the first question, in the case of the 22,000-volt line (see Figs. 3 and 7 of the paper), at unity power factor the line losses are 7.5 per cent for 2500 kw. That includes the transformer loss—I mean the copper loss in the transformers. Since the losses vary as the square of the power factor we would get 15 per cent at 0.70 power factor. Now the synchronous condenser, to bring the power factor to 1.00, requires about 4 per cent on losses. That would give us a net under full-load conditions around 3.5 per cent. But not only that. We brought the power factor at the generators from 70 up to unity, and that meant that we reduced their core losses, armature and field copper losses. An approximate estimate of the saving is about 2½ per cent, giving a total net of 6 per cent. In the case of the 110,000-volt lines (see Figs 22 and 23), the losses without the synchronous condenser—the efficiency of the line for delivering 30,000 kw., is 85 per cent, whereas with the condenser on the line the efficiency is 90 per cent. In this case the synchronous condensers have a loss of 1.3 per cent, giving a net saving of 3.7 per cent for the transmission line.

In regard to the design of the synchronous condensers, they can be designed with small air gaps, and with light bearings and bearing supports, since no mechanical load is carried; in view of these features they can be made cheaper than for the same rating as a generator or motor. Some day, perhaps, they may be built for much higher speeds and this will reduce their cost considerably.

**Professor Corey:** I have been exceedingly interested in this paper, especially because not more than a year or so ago, one of the points, only touched upon in the paper, was gone into rather completely; and more than twelve years ago another point, which has been touched upon in the paper, was gone into carefully.

I will mention first the point that was considered only a short time ago.

We have heard this evening a very complete discussion of what the synchronous condenser or the synchronous motor, either very lightly loaded or doing perhaps 70 per cent of its

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full-load work, may accomplish in the improvement of transmission conditions. A little over a year ago an investigation —a rather complete one—was made of the design of a 127-mi. (204-km.) steel tower transmission line having two three-phase circuits, maximum loss not to exceed about 6 per cent, as the power was purchased by the power user at the generating station and the tower line built by the power user, payment for the power to be made at the generating station. The amount of power required was to vary between 6000 and 10,000 kw., to be used primarily for induction motors, these induction motors to drive machinery for the crushing of about 20,000 tons of ore a day. Due to the consideration that other transmission lines were possibly to be interconnected, the voltage transmission was limited to about 80,000 volts. However, there were no taps for power along the line, nor was there more than the one generating station to be considered at that time.

The preliminary investigation indicated that 4/0 copper—the equivalent of that in stranded copper or aluminum, or aluminum of any sort—3/0 or 2/0, might be used. As has been shown this evening so very clearly, the problem in this case was not necessarily the very best possible regulation at the expense of other things; not necessarily the greatest efficiency in transmission at the expense of regulation; not necessarily the cheapest possible transmission system as regards cost of conductors at the expense either of efficiency or regulation or both. The power factor of the load was known to be somewhere around 80 per cent, due to the very large number of small induction motors. The frequency was fixed at 60 cycles, inasmuch as the generating station to be used, would be, in the future, one of a number.

Not by any means in the complete manner that has been developed in this paper, but by practically the same general principles, the general conclusion was reached that the installation of synchronous condensers at the receiving end would not only reduce the copper from 4/0 to 3/0, but it would improve the voltage regulation and at the same time increase the efficiency of transmission. A very careful analysis, using the complex quantity formula for the investigation of the power factor along the line from the generating station to the receiving station 127 miles distant, indicated that with the proper operation of these synchronous condensers doing anywhere from 50 to 70 per cent of their kilovolt-ampere capacity, it would be possible to get the best operating conditions.

Electrical energy in the form of direct current may, of course, be transmitted without introducing any of the undesirable effects due to the inductance or electrostatic capacity of the line. We start out with a given number of amperes at our generating station, using direct current, or theoretically with alternating current, with zero frequency, and we find absolutely the same

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current at the receiving end, neglecting leakage; and the ideal of the transmission engineer with alternating-current power would be to produce a condition somewhat approximating that possible with direct current. We know that is not practically possible, at varying loads, because in the matter of transmission the direct current theoretically has an advantage over the alternating current. However, I can now see, having had this evening an opportunity to look at these curves, that there were instances where such problems might have been very directly solved by the proper use of these curves rather than by going through the rather complex computations that are otherwise necessary.

The other instance that I had in mind, occurring more than a decade ago, was a case where the installation of a comparatively small synchronous motor in a mine in California was made use of to improve the power factor of the load. One of the early transmission companies, fearing induction motors would lower the power factor, offered all consumers who would use their alternating current at approximately unity power factor, the advantage of receiving 920 watts for a horse power, whether real or apparent. A well-known engineer in San Francisco said, "Very good. If we can get 920 apparent watts for what we ordinarily pay for 746, we will see to it that we get 920 real watts,"—which was accomplished by the installation of a synchronous motor. This synchronous motor, except at such times when the power was off—and in those days the transmission lines gave more trouble than they do today—was belted to a steam engine, and when the power was off the synchronous motor was operated as a generator and the mine was kept free from water. It was necessary to prevent the mine being flooded even if the transmitted power should be off only for a few hours. The result was that for a number of years the synchronous motor was ordinarily operated without doing any work whatever, and the power factor of the load was maintained at 100 per cent. The result was that the buyer of the power did receive 920 real watts, for which he only paid the price of 746 watts. I do not remember how many times that condenser or unloaded synchronous motor paid for itself every year, but I remember that it was used for a number of years.

I am only mentioning this because in this case the particular advantages of the operation of synchronous motors though lightly loaded or practically unloaded, were availed of to improve the conditions of transmission—improving the conditions in regard to both efficiency and regulation of voltage; and while I have not perhaps had an opportunity of fully studying the paper that has been presented this evening, I can see that in the first case mentioned the solution of that problem might have been made graphically from the curves presented by Mr. Hagood instead of being worked out in that one isolated case.

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I would like to add this other point. Due to the careful investigations of Dr. Steinmetz's formulas for distributed capacity, also introducing the factor which it is possible to introduce in Dr. Steinmetz's formulas, namely, the amount of energy loss due to leakage between conductors, and going one step further than Dr. Steinmetz has gone, representing the results of some of his formulas graphically, it is possible to determine the power factor at any place you wish in your transmission line from your generating station to the point of delivery. If your line is 300 miles long it is only necessary to go through an elementary graphical construction as you would in determining stresses and strains in a structure, to ascertain what the power factor is at any point, simply substituting in the formula, whether the point under discussion is one mile from the generating station or 299 miles. So there we see the opportunities and the possibilities of further ascertaining the facts, and the desirability of introducing these synchronous condensers.

There is another point brought out that appeals to me especially. Not very many years ago it was generally understood that if we attempted to transmit power great distances where the charging current would be abnormal there was only one thing to do, namely, to reduce the frequency, if the voltage were maintained of sufficient magnitude to reduce the line losses. But one can see by viewing the curves that have been shown by Mr. Hagood that this is not necessarily true. Possibly we will be able to solve a great many of our problems at 60 cycles that we thought a few years ago could only be solved at one half that frequency or even one-third or one-sixth.

Not only are these few isolated instances that I have mentioned covered by the work that has been done by Mr. Hagood, but his work covers all other problems of a similar character.

**L. P. Jorgensen:** In substations where no motor power is required the synchronous condenser is undoubtedly the most practical device that can be used successfully for voltage control; but in stations where the principal use for the power is to drive motors these motors should be so selected that part of them are synchronous and part induction. It is seldom possible, nor desirable, to have all motors on a transmission system of the synchronous type, as the starting requirements may be such as to exclude synchronous motors, and it may not be practical to provide direct current for excitation. Where large motors are to be dealt with the extra outlay and complication for excitation does not amount to so much, and it is therefore of advantage to equip them with devices for voltage control to compensate for the lagging current of the smaller induction motors and other apparatus. The voltage in use at present on some of the largest transmission lines has reached the limit. This limit is set by the amount of corona loss permissible, so it is not possible to improve per cent of voltage drop by increasing the voltage, as this cannot be done. The critical voltage de-

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pends upon size of conductors and elevation above sea level, and the limit of voltage has already been reached in several cases. The limit at sea level is somewhat above 120,000 volts where the amount of power is large enough to require conductors larger than 4/0. A few months ago I had occasion to visit a place and do some work in connection with a power transmission where 50,000 volts was the upper limit of transmission voltage, principally because of the high altitude, the average of which was 14,000 ft. (4270 m.). The lowest point on the line is the power house, located at 12,200 ft. (3720 m.) above sea level, and the highest substation is located at nearly 16,000 ft. (4880 m.) elevation. The line runs for the greater part of the distance of 120 mi. (193 km.) over a comparatively flat plateau of 14,000 ft. (4270 m.) elevation. This place is called the roof of the world, and is up in the Andes mountains in Peru. The load on this system is mostly motors driving copper mining machinery to the extent of about 10,000 h.p., requiring a conductor of No. 1 size cable. The motors are divided up between synchronous and induction in such a way that the power factor will be under complete control by means of automatic voltage regulators adjusting the excitation of the synchronous motors.

**Herbert W. Crozier:** I want to ask a question of Mr. Jorgensen. Did I understand you to say that 50,000 volts was the limit?

**L. P. Jorgensen:** Yes, because only 10,000 h.p. was to be transmitted. You could not afford to take larger than No. 0 cable, and at that diameter you cannot get above 50,000 volts.

**J. P. Jollyman:** One of the chief functions of the synchronous condenser in the ordinary transmission system is, as Mr. Hagood has pointed out, to help hold up the voltage. As the load on our system grows, frequently we run into conditions where excessive voltage drop limits the amount of the load which may be successfully carried at some point.

There is also another factor in the holding up of voltage which Mr. Hagood only touched on very briefly, but which to those of us who are connected with 60-cycle systems is a very important matter, and that is the charging current of the line, and its effect in balancing or neutralizing the lagging current due to the ordinary commercial load. The effect of this charging current is very considerable. We have at the present time in this vicinity a number of high-tension transmission voltages—60,000 and 100,000. At 60,000 volts the charging current amounts to about 18 kv-a. per mile. In other words, a company such as the one with which I am associated, operating some 1200 mi. (1930 km.) of 60,000-volt line, has a charging current of over 21,000 kv-a., and this is sufficient to raise 29,000 kw. of 0.80 power factor load to unity. That of itself has a very important effect in holding up the voltage of such a system. Now a 100,000-volt system has a very much higher charging current. As the voltage and the current go up your kilovolt-amperes go up. The charg-

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ing current for a 100,000-volt line is about 52 kv-a. per mile. In other words, a 300-mi. (483-km.) line would have some 15,000 or over 15,000 kv-a. wattless leading current component, which would assist in balancing the bad power factor of the ordinary commercial load. This wattless component on 300 miles of 100,000-volt line would balance 21,000 kw. at 0.80 power factor load, bringing it up to unity. I believe that the charging current which, as you see, is no small amount on systems which are operating, has a very important effect in helping to hold up the excitation. The excitation on a transmission system is somewhat analogous to the mechanical condition of the cantilever beam. If the excitation is supplied entirely at the generating station it is somewhat analogous to a cantilever beam supported at one end and loaded at the other. Such a beam must necessarily sag at the loaded end. The voltage cannot be anything but lower at the receiving end where you have purely load and are supplying no excitation in the way of synchronous machinery. The variations in voltage with the variations in load are somewhat analogous to the variations in the sag of such a beam with a varying load. To steady that beam you may supply some support at the free end. In other words, you may apply some synchronous machinery at the receiving end. It is obvious that you may *steady the variations* in the deflections of that beam with very much less support than would be required if you wanted to raise the beam up to the same level that it was held at the fixed end; and that is, as near as I can suggest, a mechanical analogy to the transmission problem in the operation of synchronous condensers. It is obvious that a beam supported at both ends will have less sag if it is loaded uniformly than if it is supported at one end as is the case in the transmission system. If you have synchronous apparatus at both ends the voltage drop will be less throughout the system. It think it would be well for any one having to do with the design of transmission systems to consider always the effect of their charging current, and to bear in mind that it is a very considerable amount, very closely approximating 18 kv-a. per mile for 60,000 volts at 60 cycles; and 52 kv-a. per mile for 100,000 volts and 60 cycles. There have been some transmission systems projected recently where the charging current is going to prove a very serious problem to handle properly. My own opinion in the matter is that you should not ordinarily attempt to operate a single transmission circuit with generators which are less in capacity than the charging current. In the system on which we are working at the present time the kv-a. capacity of a generator is approximately double the charging current on the line, and I anticipate that we will not be very much bothered by variations in load or bringing the empty line up to voltage.

**Herbert W. Crozier:** Mr. Jollyman apparently has given this matter of the charging current a very considerable amount of thought. The point I want to draw attention to in connection

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with the use of synchronous condensers for the regulation of the line is the matter of safety. We all know that the loss of load due to excitation and opening of circuit breakers and other things causes a very considerable rise of voltage at the substations; and the use of the synchronous condenser controlled by the automatic voltage regulator is certainly an element of safety, because there is something there which will make a change in the conditions in the end, assuming of course that the synchronous condenser is so installed as to remain connected to the transmission line. I remember two or three cases where very disastrous results occurred, due to the opening of the end of a transmission line, causing the wrecking of lightning arresters and general destruction of such apparatus as still remained connected.

**L. N. Peart:** We have a 60,000-volt line approximately 200 mi. (322 km.) long, and I can confirm some of Mr. Jollyman's remarks very strongly, because I have just made some experiments on the power factors of this line, and also some corrections obtained by using some turbines at one end of the line as synchronous condensers. We have about 200 miles of 60,000-volt line, fed at one end by a hydroelectric station, and at the other end by a steam auxiliary. The hydroelectric end is 16,000 kw. capacity; the steam end is about 8000 kw.; and close to the steam end at the outer end of the line we have the oil fields, which furnish a very highly inductive load. The power factor at the oil fields loads is approximately 70 per cent, and when we first started the transmission line the power factor of the transmission line at the power house was 62 per cent leading. That was before we had much oil field business. As the oil field business came on—and I might say that the power factor of the oil field load is not much better than between 60 and 70 per cent—it never gets over 70—the power factor at the transmission end at the power house gradually approached unity, and at present, it is very close to that. Now operating the turbines in Bakersfield at 8000 kw., allowing them to float on the line with a little steam and adjusting the exciting current, we are able to keep the voltage regulation of the system very nearly constant, that is, we can hold the voltage in Bakersfield and at the power house end practically the same, with a rise of voltage in the middle of the line of about 8 or 10 per cent. Recently, due to the failure of some of the hydroelectric machinery at the generating end, the water end, it was necessary to carry the entire load from the Bakersfield end. You will appreciate that without any feeder voltage regulators on the system, the step-down transformer stations are connected through the proper taps to the line so that we get the proper voltage grading; in other words, near the power house the transformers are on a higher tap and gradually decrease down the line to take care of transmission drop. Feeding from the steam end, matters were reversed, and it was a question whether we were going to get any voltage regulation; but operating the hydroelectric generators as synchronous condensers,

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and feeding from the Bakersfield end with the steam generating machinery, we were able to keep suitable voltages at all points. That, I think, furnishes a very good illustration of Mr. Hagood's point.

**J. P. Francis:** There is one other point in the operation of a synchronous motor as a condenser that it is well to consider, and that is, that by limiting the range of the exciter voltage, so that when the voltage of the transmission line is too high the regulator is lowering the voltage of the motor, the excitation of the synchronous motor will not be reduced too greatly, causing the machine to fall out of step if the load increase suddenly. Also, the upper limit of the exciter voltage should not be high enough to burn the regulator contacts when the synchronous machine is boosting.

**R. C. Powell:** Mr. Jollyman mentioned that the charging current in the line should be taken into consideration. The point is, as I understand it, that the charging current will help out the generators but not the line.

**Professor Corey:** It ought to help out both.

**R. C. Powell:** That is, with a simple line.

**H. Y. Hall:** I think Mr. Jollyman's point was more in respect to regulation. There is no question but that the charging current of the line will help out the regulation.

**R. C. Powell:** I don't believe I can agree with you, for the reason that the regulation will be the difference between the voltage and no-load voltage. At no-load the voltage at the receiving end will be higher than at the transmitting end, due to the charging current. Now if the load comes on the charging current is constant, and the voltage rise due to the charging current is constant, so where you would start with 100,000 volts with no-load and get 120,000 at the receiving end, at full load you would have 20,000 drop, and you would have 100,000 at each end; but your regulation is the same.

**J. P. Jollyman:** I would say that the principal effect on the distributing system is naturally the improvement of the power factor of the load that the generators carry. The charging current is roughly one-half as effective in helping out the line as would be a synchronous condenser at the receiving end. The charging current is distributed, but it is not far, in general, from the effect of either the equivalent leading current load at the center of the line, or one-half of the load at the extreme end of the line. You will frequently find that a transmission system which starts out purely as a transmission affair, and transmits a very large percentage of its power over practically its entire length, grows into a system in which more or less load is taken off along the line; and in that case the charging current to a certain extent neutralizes the lagging current of the load, the load being somewhat distributed, and the charging current being entirely distributed. The principal effect of the charging current, as I stated, is an improvement in the

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generator power factor, which is a very important matter; and it is perhaps in its effect on the efficiency of transmission roughly half as effective as a concentrated synchronous condenser of the same capacity at the load point.

**A Member:** I would like to ask Mr. Jollyman if the value he gave of 18 kv-a. for a 60,000-volt line and 52 kv-a. for 100,000 volts, has a certain regard for the spacing, and cannot that be varied by altering the spacing?

**J. P. Jollyman:** I think if you will consider the practical cases of transmission at 60,000 volts you will find that the spacing is usually, in modern construction, about five or six ft. (1.5 to 1.8 m.), and for 100,000 volts the spacing is nine or ten ft. (2.7 to 3 m.), and is frequently in a vertical plane, which means that the average spacing of the phases is about one and one-third times the distance between the two wires. I have found by plotting the values of the charging current in relation to the ratio of the diameter of the wire to the spacing, that the change in the value of the charging current over the range of actual construction such as is generally employed by operating companies, is very small. If I remember correctly, the charging current per mile (1.6093 km.) for 10,000 volts over the range of construction ordinarily employed varies from about 0.028 of an ampere to about 0.031. The values that I gave were based on 0.03 of an ampere for 10,000 volts per mile. The charging current does not change very rapidly over the range of spacings, with the size of wire ordinarily employed. If you have a rather small spacing and very large conductors it would be a little different from what it would be if you had large spacings and very small conductors; but the change is really so small, and there are so many other things that enter into the exact determination of this value, that these figures are sufficiently accurate for ordinary calculation. You would not select the size of a generator down to anything smaller than 500 kilowatts, and these values will give you the charging current within a few hundred kilovolt-amperes of the actual value.

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# THE DEVELOPMENT OF THE ELECTRIC MINE LOCOMOTIVE

BY G. M. EATON

ABSTRACT OF PAPER

The paper traces, largely by means of pictures, the course that has been followed in developing the mine locomotive to its present condition. The paper is limited to locomotives for operation in coal mines. The two main factors which have directed the development are, first, the demand for increased entry capacity, and second, the exploitation of thin seams. The early machines were high, and of irregular outline, whereas later machines are compact and strong, yet accessible, and easily inspected and overhauled. Various types of framing are illustrated. Locomotives with two and three axles in rigid wheel base, and also tandem locomotives are shown and described. Reference is made to various methods of connecting the motors by which the adhesive weight is used to full advantage. Gathering locomotives, with vertical and horizontal reels, both axle-driven and with independent electric drive, are illustrated, and some of the problems of gathering work are briefly discussed. There is also brief reference to various types of motors with different methods of lubrication, as well as some reference to sleeve vs. frictionless bearings. The paper closes with a few tendency curves, and attention is called to the lines of future development, which these curves apparently indicate.

THE evolution of mine haulage has been directed at every stage by the demand for increased capacity. This clamor for more tons at the tipple is successively relegating to the discard, both man and animal haulage.

Available headroom plays a close second to output requirements in moulding the development of the locomotive for coal mines. Wherever the seam is too thin to permit free passage for the mule, the electric locomotive is the logical solution, and as thicker seams are worked out the field must become more and more monopolized by this type of motive power.

The thin seam, however, is not the only logical field for mine electrification. In fact, the earliest applications of mine locomotives were made for service in thick seams, where the chief aim was increased tunnel capacity.

Fig. 1 shows the first locomotive supplied for mine service in



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1,896 by one of the large builders of this class of machine. It weighed 43,550 lb. (19,754 kg.) and was equipped with two 75 h.p. motors driving through double reduction gearing and side rods. The block displacement of this machine, *i.e.*, length × height × width = 582.5 cu. ft. (16.5 cu. m.). Block displacement divided by h.p. = 3.88 cu. ft. (0.114 cu. m.) per h.p. A modern machine equipped with the same capacity of motors would have only 231 cu. ft. (6.48 cu. m.) block displacement or 1.54 cu. ft. (0.043 cu. m.) per h.p.

This is a measure of the increased demand for space economy in mine locomotives. This particular machine, shown in Fig. 1, was scrapped April, 1913, after 17 years of service.

Fig. 2 shows a locomotive produced in 1913 and is presented to emphasize the radical improvement over Fig. 1. A few of the main features wherein this improvement lies, are listed below:

1. Electrical equipment designed for mine service.
2. Staunchness of general construction.
3. Maximum protection of apparatus, without sacrifice of easy inspection.
4. Single reduction gearing.
5. Low height.
6. Short overhang.
7. Compact design.

All these features may be summed up as those contributing to produce a machine that will do its work reliably with a minimum of out-of-service periods.

Very few locomotives of the scraggly outline shown in Fig. 1 were put out for coal mining service. It became evident at an early stage of the development that a mine locomotive must be capable of withstanding severe collisions, and must sustain a minimum of damage from falling roof and similar emergencies. The locomotive design, therefore, soon settled down to an iron-clad machine with motors under cover, and virtually under an inverted box. This was for many years considered the ideal and only way to build mine locomotives, and is still thus regarded by some today. Cast iron was the almost universal material employed in the locomotive framing.

Fig. 3 and 4 show typical machines of the period, the first with frames inside the wheels, and the second with frames outside the wheels. Thus far the locomotive was used for nothing but main haulage, animal haulage being practically universal for gathering. This was a rather long-lived stage in the develop-

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ment of locomotive framing. The causes for gradual changing of ideas were fundamentally two. First, the entry of locomotives into gathering service, and the consequent necessity for lighter locomotives to negotiate flimsy, rough track in rooms, and second the demand for greater strength to withstand the rough and tumble gathering service, and increasingly severe main haulage service.

Sections were trimmed smaller and more care was taken to put the metal where it would do the most good. It was then realized that it would be an excellent plan to produce locomotives which if damaged in a wreck, could be repaired in the mine blacksmith's shop. Fig. 5 shows a locomotive with plate and angle framing, which meets this requirement to quite a degree. Such a machine is far lighter for a given strength than a cast iron frame machine. There is, however, a rather definite maximum weight limit beyond which it proved to be poor economy to push this type of machine. Larger machines when laid out with plate and angle construction proved to have such high weight economy that it was necessary to ballast them to give the weight required for adhesion, and when laid out with cast iron members the strength was sufficient for all ordinary requirements.

A step further with this general type of construction is shown in Fig. 6, where bent flanges replace the angles shown in Fig. 5.

In case of a collision with these plate steel frame locomotives, a certain amount of bending and buckling may occur, but the framing can be straightened up in the blacksmith's shop, and the locomotive returned to service with a minimum of delay.

Another type of frame which is extremely substantial and which lends itself to heavier locomotives consists of a single heavy rolled steel plate cut out to the desired shape. This type of frame is practically unbreakable, and it has been used quite extensively.

A very interesting combination of cast iron and structural steel frame is shown in Fig. 7. Several such locomotives have been turned out and have given good service. In case of a bad crumpling of the frame, the operator can secure a commercial angle and bar or he can carry a length of each in stock and can make quick repairs on the ground.

If the end casting breaks he can secure a new one and make replacement himself without an extensive disassembly of his machine. He can also lengthen the locomotive wheel base, should he so desire.

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The next step was to cast steel bar frame shown in Fig. 2. This frame has been thoroughly demonstrated in steam locomotives and in electric locomotives for main trunk line railways. Its main advantages have been summarized under Fig. 2. Figs. 8, 9, 10, and 11 show the convenience with which such fundamental parts as brake shoes, armature bearings, oil wells, commutators, etc., can be inspected and maintained. The motor is open to air circulation and will therefore perform a given all-day service with less temperature rise than when operating in a more nearly enclosed space. For purposes of quick production the cast steel bar frame was at first considered inadaptable. If a large, special steel casting must be made for each new locomotive, quick production is difficult. Fig. 12 shows a locomotive with cast steel bar frame in which two pedestal openings at the left-hand end are cast in embryo as it were. By machining out the lower chord of the frame in the wake of the proper pedestal opening, the same casting can be used for either inside or tandem-hung motors. This casting is also designed to suit either inside or outside frames. These castings can then be carried in stock in the more popular sizes of locomotive and comparatively quick shipments are possible. This type of frame lends itself to a certain amount of repair at the mine. It is, however, based more particularly on the principle of making a frame that will resist damage to a greater degree than plate and angle construction, at some sacrifice of the ease of making permanent local repairs. A bent frame can be heated and straightened at the mine forge. The chance of a frame breaking is very remote, in fact out of the large number of locomotives with this type of frame produced to date by one large concern, only one case of cracked frame has been reported. This occurred in a severe collision, and the frame was replaced.

In steam locomotive practise, the great length of the cast steel frames, and the heavy strains incidental to high speed and high power, cause considerable frame breakage. Welding by either the thermit or the electric process proves very satisfactory, and in the event of breakage in mine service could be employed. The thermit process would be the most practical, especially in small operations, on account of the simplicity of the necessary equipment.

To meet the demand for the maximum drawbar pull with a minimum of weight, a variety of types of locomotives have been introduced. The first locomotive illustrated in Fig. 1 shows one

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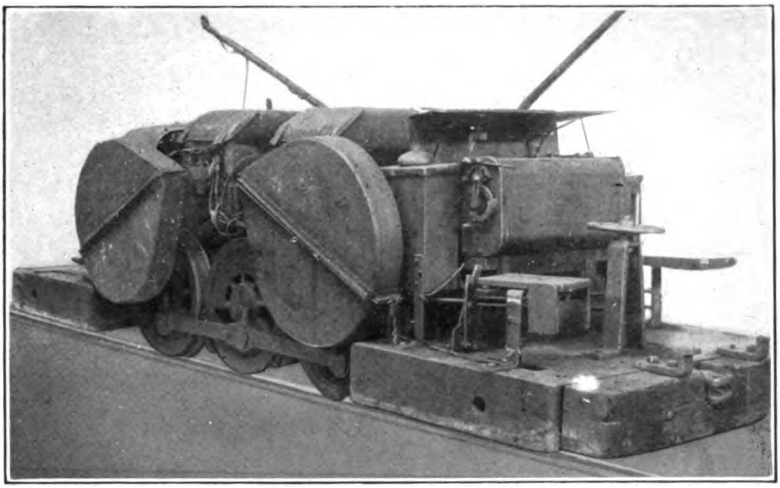

FIG. 1 [EATON]

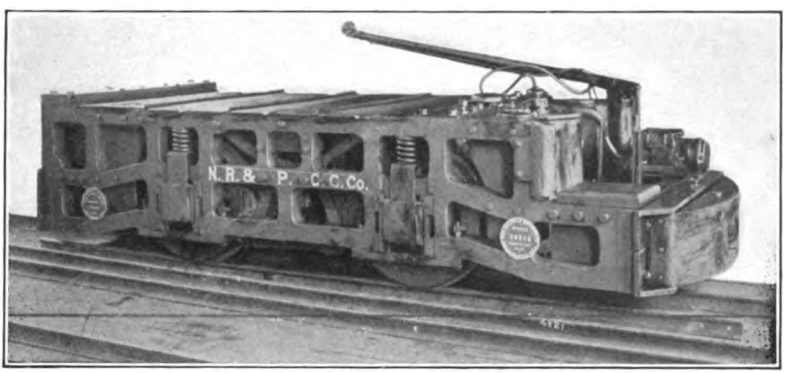


FIG. 2 [EATON]

FIG. 3 [EATON]

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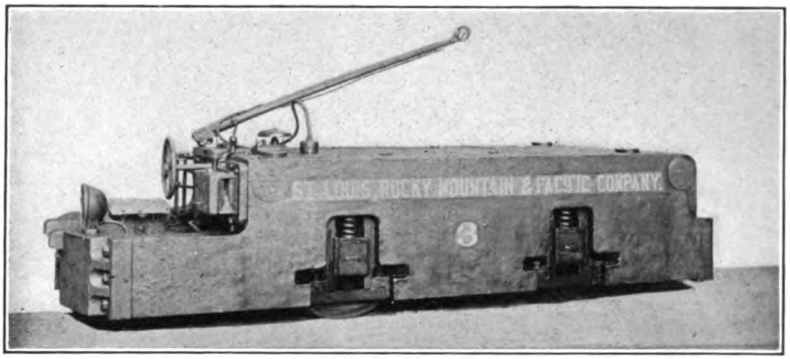


FIG. 4 [EATON]

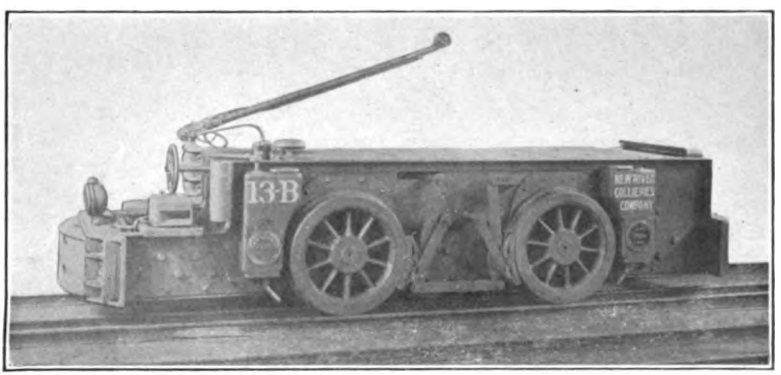


FIG. 5 [EATON]

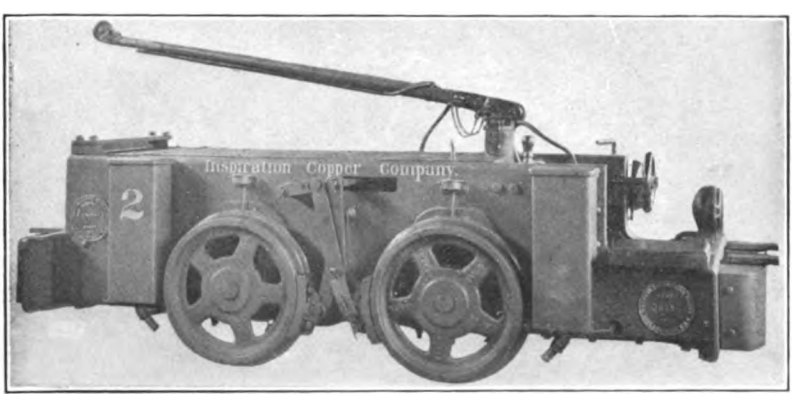


FIG. 6 [EATON]

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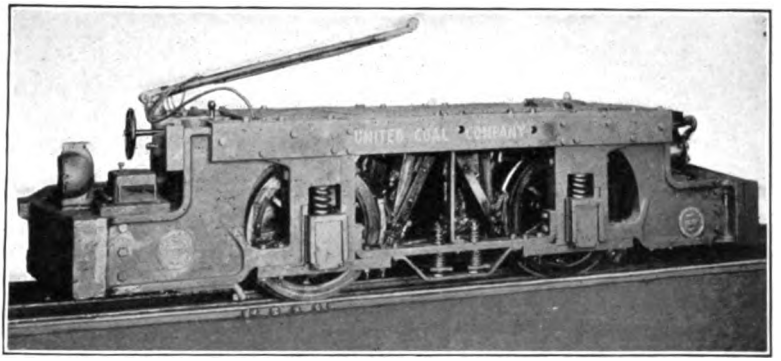


FIG. 7 [EATON]

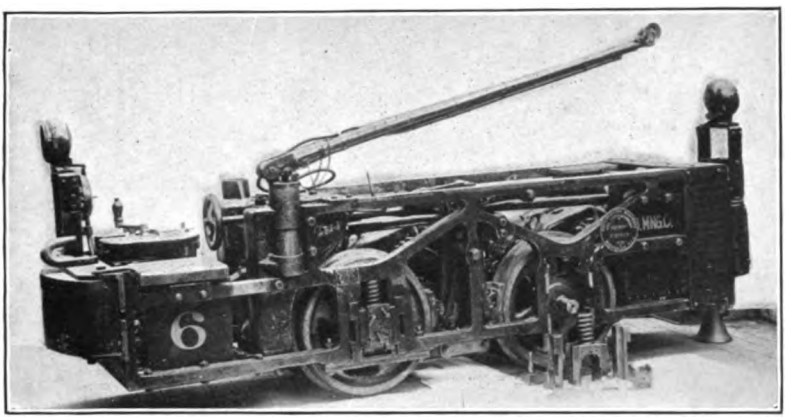


FIG. 8 [EATON]

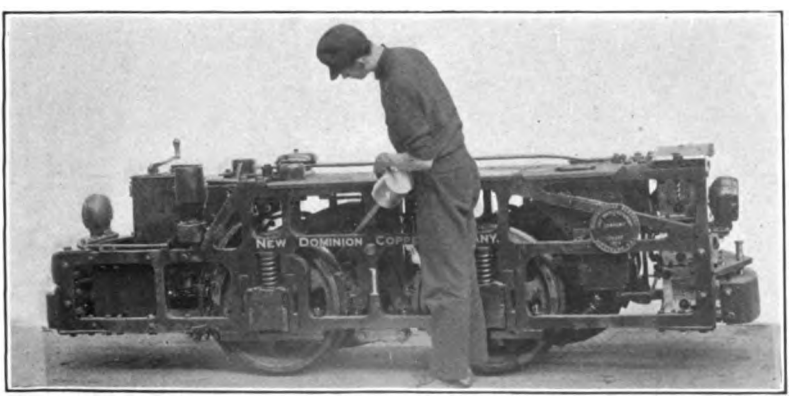


FIG. 9 [EATON]

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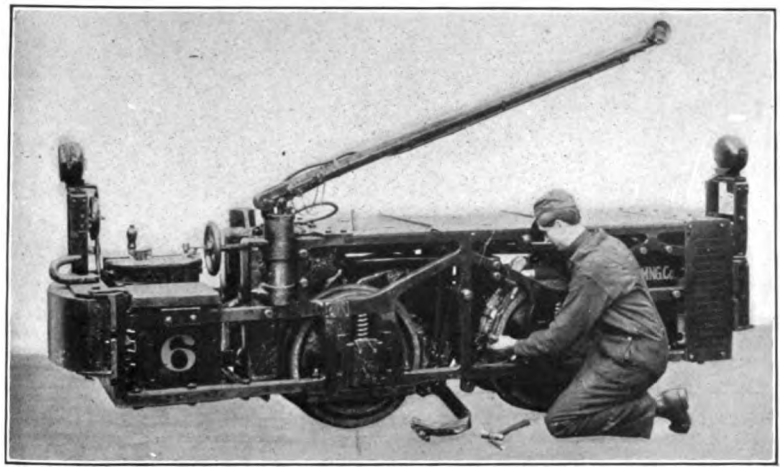


FIG. 10 [EATON]

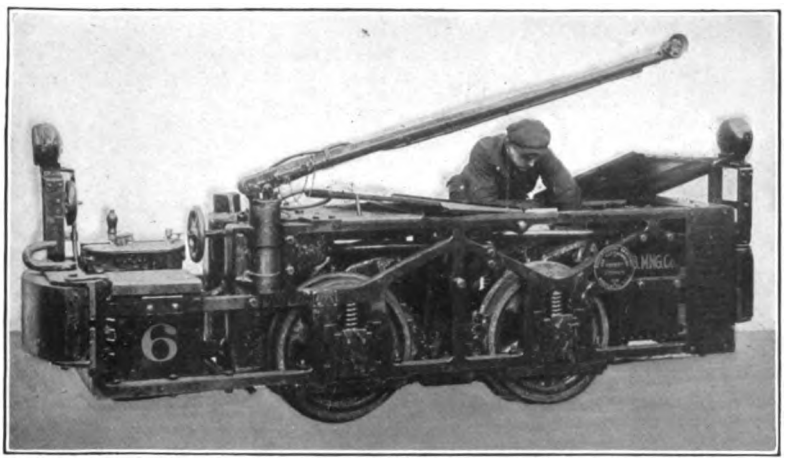


FIG. 11 [EATON]

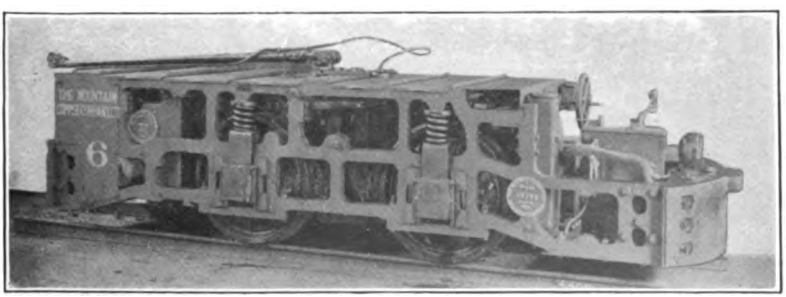


FIG. 12 [EATON]

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effective method, namely the coupling of the axles by means of side rods. In this machine, rod drive was adopted as a ready means of applying standard industrial motors rather than for the purpose of securing maximum draw bar pull.

Fig. 13 shows a locomotive equipped with a single motor geared to one axle and rod connected to the other, to secure the total weight for adhesion. In this type of machine, the advantage of simplicity and smaller number of parts is secured with the sacrifice of the advantage of the series parallel connection.

The same general result is secured by connecting the axles of a single motor locomotive by one or by two chain and sprocket systems, instead of by side rods.

Another method consists of gearing a single motor directly to both axles. The motor may have its shaft parallel with the axles with double reduction spur gearing, as shown in diagram

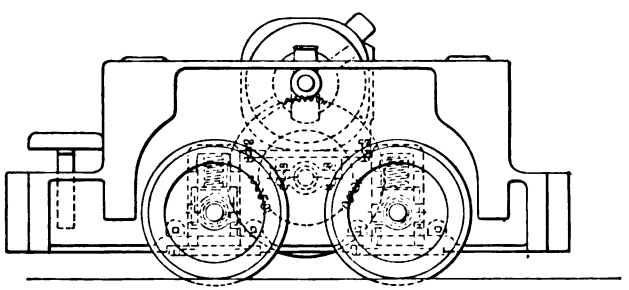

FIG. 14

in Fig. 14, or the motor shaft may be longitudinal, with bevel gearing.

In all of these arrangements, the reduced complication of the single motor is more or less offset by the great complexity of the transmission system.

In the early locomotives, cast iron wheels with chilled treads were universal. The introduction of steel tired wheels was first made to secure a longer wheel life. These wheels, however, also contributed the advantage of greater adhesion, particularly with sand. The ultimate possibility in drawbar pull with a given weight of locomotive is of course the rack rail machine.

In the pursuit of greater capacity on a given gage, or to suit a fixed cross-section of entry, the next logical step after maximum drawbar pull is secured from two axles, is, in mine service as in trunk line locomotives the addition of more axles. The history of the mine locomotive, however, is different from the trunk

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line machine in that the first step which was broadly applied in the mine locomotive was from two axles to four axles and later in a few cases to three axles. This of course was due to the almost universal existence of sharp curves that strictly limited the available wheel base. Fig. 15 shows a tandem locomotive. This particular machine is not necessarily permanently coupled. It is equipped with a single controller on the left-hand half, which handles all four motors. Flexibility of operation is secured by equipping the right-hand half with a controller capable of handling two motors only.

The locomotives can thus be operated as single or double units according to the exigencies of the service. Also in case of injury to one half, a minimum of reduction of mine output occurs.

When the main entry is laid out with liberal curves, it is possible to have three axles arranged in a single long rigid wheel base. Fig. 16 shows a locomotive of this class.

In developing low coal veins it becomes important to keep down the overall height of the locomotive to an absolute minimum. Fig. 17 shows a locomotive in which the flange of the wheel is the highest part of the machine. These low locomotives are of course particularly desirable where bad roof conditions make it inadvisable to blast down the roof to secure added head-room. Such machines are also advantageous in gathering from low rooms as lack of head-room makes it difficult for men to push out the cars. This brings up the general subject of gathering locomotives.

At first the gathering locomotive was simply a small edition of the main haulage machine. Such a locomotive of course requires in the rooms steel rails more or less effectually bonded, and a trolley wire.

For various reasons it is often undesirable to introduce these features into the rooms. The cause may be danger to the miners gaseous condition of the mine, or expense. These objectionable features are partially overcome by equipping the locomotive with a reel carrying a single conductor cable, as shown in Fig. 18, and running steel rails, but no trolley wire into the rooms. A still further elimination is secured by fitting the reel with a double conductor cable, when unbonded steel rails, or wooden rails, can be employed. With wooden rails, the locomotive weight is practically limited to about five tons.

Another method of eliminating the undesirable features is the application of the storage battery to the gathering locomotive. This is a comparatively recent development, but with the modern storage battery with its ability to resist mechanical shocks, the

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locomotives of this class have given promise of being thoroughly practical.

The locomotive can gather from the rooms without entering them if a traction reel or crab is installed on the locomotive, as shown in Fig. 19. This type of locomotive can haul cars from the rooms, but of course cannot deliver empties to the face.

A comparatively small number of locomotives have been produced on which both types of reel are applied.

The earliest form of cable reel was driven from one axle by a chain. Two general types are in use, one with its axis vertical, as shown in Fig. 20, and the other with its axis horizontal as in Fig. 18. Both have an inherent weakness. When the rooms dip to the entry, it is necessary to brake the locomotive when bringing the car out. If the wheels from which the reel is driven slip on the rail, the cable slackens, and is liable to be run over and cut in two. To overcome this, two types of reel have been produced, one with long clock springs, which are wound up on entering and which unwind and recover the cable on the return. A later general type is driven by an independent motor which is connected across the line through a resistance and is in effect an electrical spring.

There are here as in the case of the axle driven reel the vertical axis type and the horizontal axis type as in Fig. 21. In the latter type the armature is inside the reel. Fig. 22 shows the method of removing an armature. The resistance used with this type of reel is the heater type of resistance where the resisting element is mica insulated and hermetically sealed in a steel tube.

A traction reel with bevel gear drive is shown in Fig. 23 in rather more detail than in Fig. 19. The reel can haul through an angle of slightly over 180 deg. or over 90 deg. from the track on either side.

As locomotive development has been perfected, attention has focussed more and more on facility in overhauling. For example, in the early types of locomotive with frames outside of the wheels, it was necessary in order to remove a journal box, to drop the axle or jack the locomotive till the box was entirely clear of the side frames. Fig. 4 showed a locomotive where this is necessary. Various designs were later adopted where this is avoided. Fig. 8 shows another solution where the pedestal gibbs are interrupted and when the locomotive is jacked sufficiently to slack the spring the segmental pedestals are out of mesh and the box will slide out freely. This feature is representative of many details that have been similarly improved.

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As has been previously stated, the earliest locomotives were electrically equipped with apparatus designed for other types of service. As the electrification of mines gained headway, it became evident that the severity of the service demanded more sturdy equipment. The motors received the first attention. Some of the leading types will be reviewed. The motor used on the locomotive shown in Fig. 1 was a bipolar type and is shown in Fig. 24. Fig. 25 shows a motor split through the axle. A very large number of locomotives are running with motors of this class. The overhauling of such motors and particularly the renewal of axle bearings is more difficult than with many of the later designs. This motor in common with all the earlier types is arranged for grease-lubrication of both axle and armature bearings. Such bearings in general require the addition of lubricant at least once a day, and sometimes much oftener. With proper attention, however, they have given very good results.

Fig. 26 shows a motor with independent axle caps. Both axle caps and suspension attach entirely to the lower half of the frame. This permits of ready overhauling of the motor. The excellence of this general arrangement was first proved in city and interurban railway service and it proved equally successful in mine service and has been widely adopted.

The great advantage of oil and waste lubrication over the earlier grease lubrication was proved in the street railway motor. Its wide success in this field led to its introduction into mine service. Fig. 27 shows a mine motor so equipped.

This experiment was entirely successful and was also widely adopted. This form of lubrication in combination with high-grade bronze bearings is in fact so thoroughly successful that it is still considered by some locomotive builders, to be the best all around solution. In one complete line of motors that has been on the market for some years, there has been no case reported where this type of bearing has failed. Other builders in discarding grease bearings have standardized on various well-known types of ball or roller bearings. It is to be hoped that the comparative merits of the two general types of sleeve versus frictionless bearings will be brought out in the discussion.

In addition to the mechanical improvements of the motor, the electrical designs have made a great advance. The most notable feature has been the addition of commutating poles. This is of particular advantage in mine service, where there is little or no coasting, so that there is no chance to polish the com-

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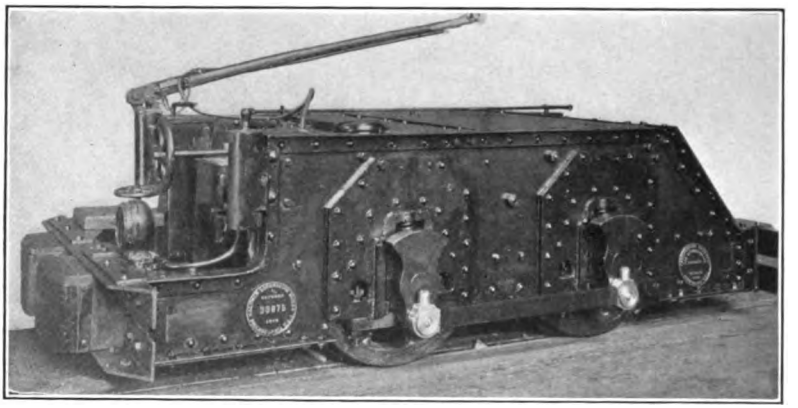

FIG. 13 [EATON]

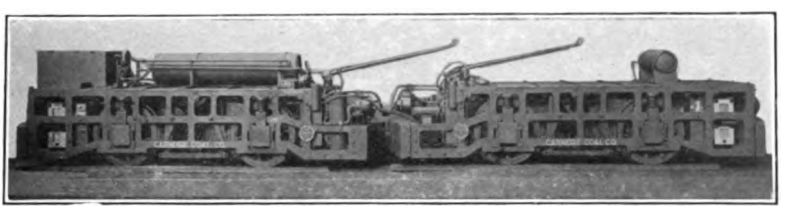

FIG. 15 [EATON]

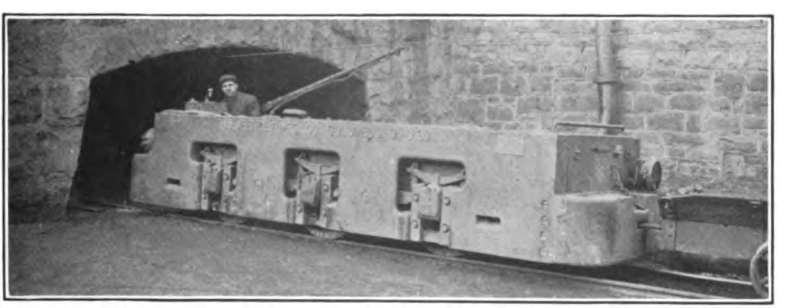

FIG. 16 [EATON]

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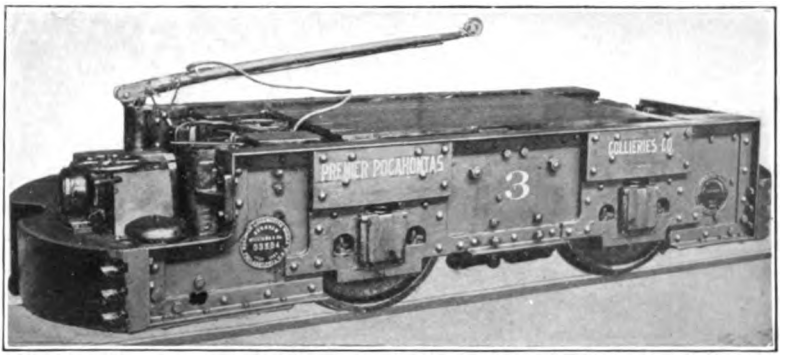


FIG. 17 [EATON]

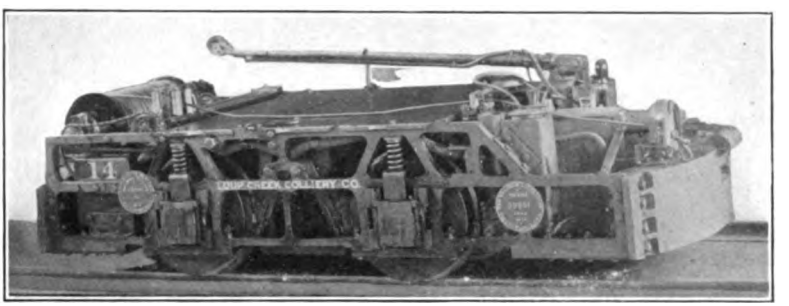


FIG. 18 [EATON]

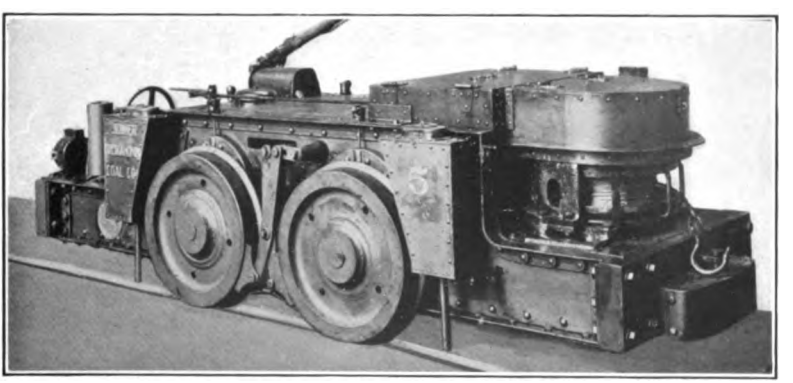

FIG. 19 [EATON]

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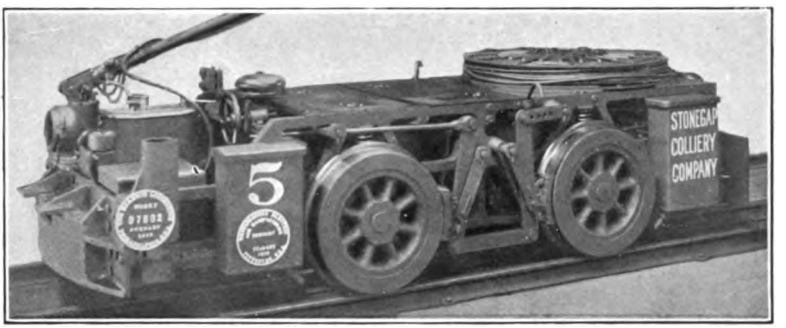


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FIG. 20

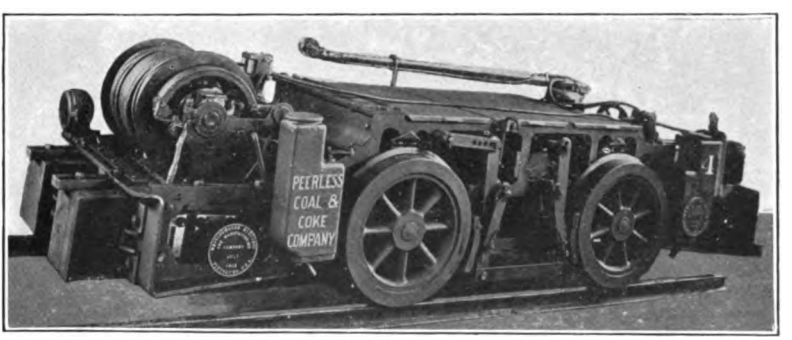


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FIG. 21

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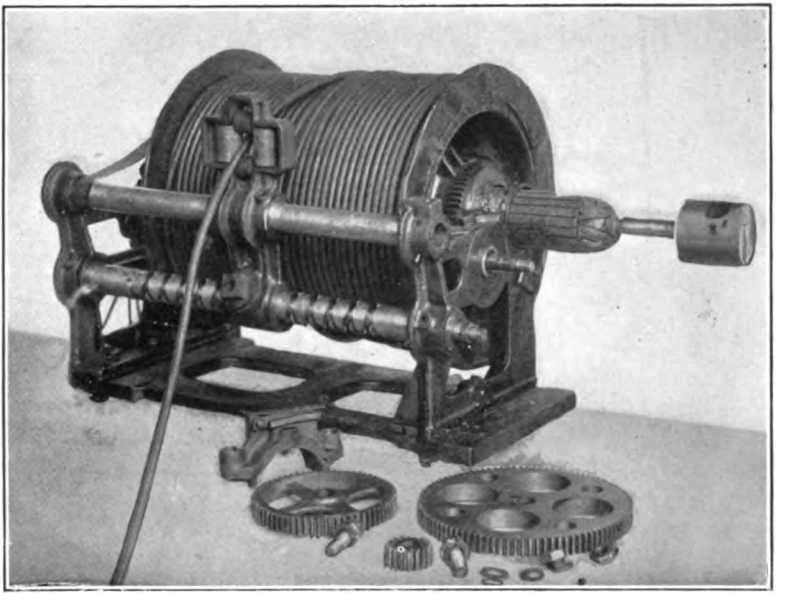

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FIG. 22

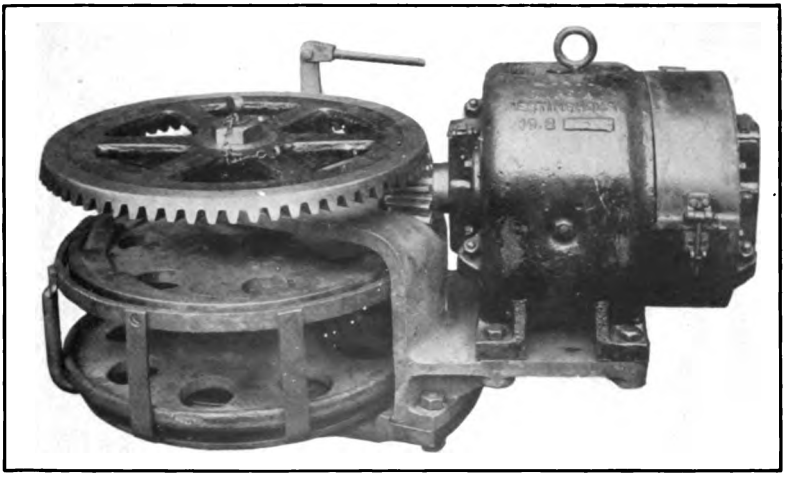

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FIG. 23

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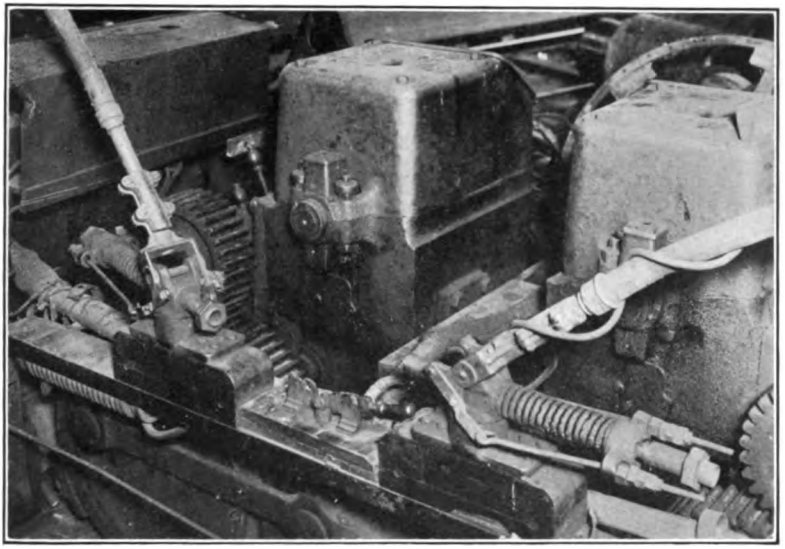

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FIG. 24

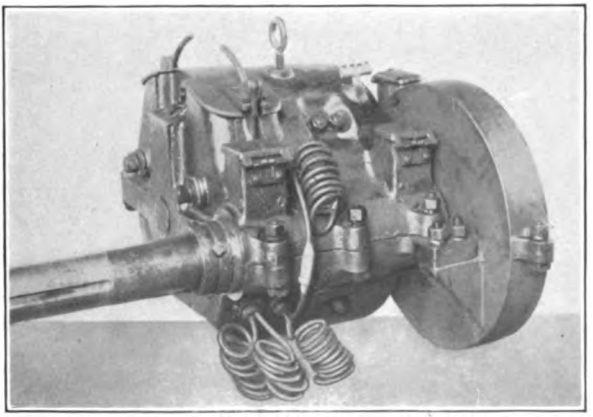

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FIG. 25

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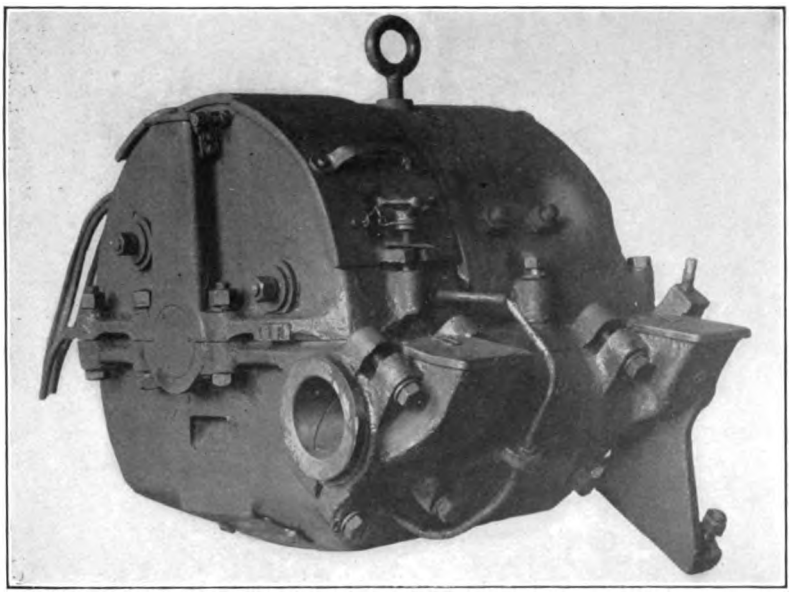

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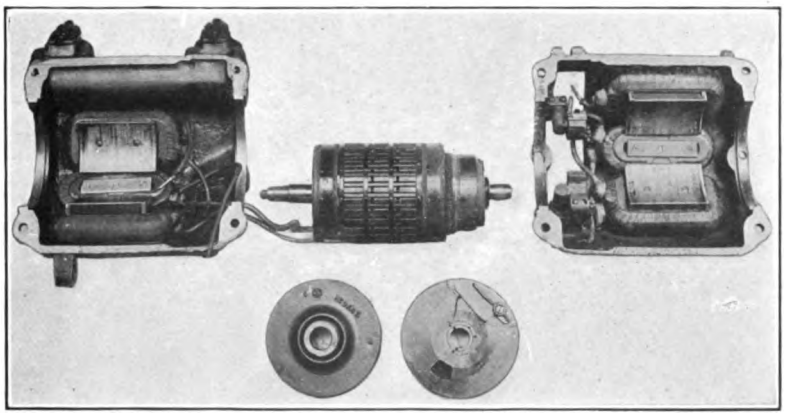
FIG. 26



[EATON]

FIG. 27

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mutator. In such service, the best of commutation is essential. Fig. 27 shows a typical arrangement of motors with commutating poles.

The motors of today are designed with particular reference to securing a high continuous rating, since this means the greatest tonnage delivered at the tipple.

In the early days the resistance gave a great deal of trouble. Various forms of cell and ribbon type resistance were employed. These were gradually superseded by grid resistance, till today this is the accepted standard. The first introduction of grid resistance, however, was by no means the solution, and both

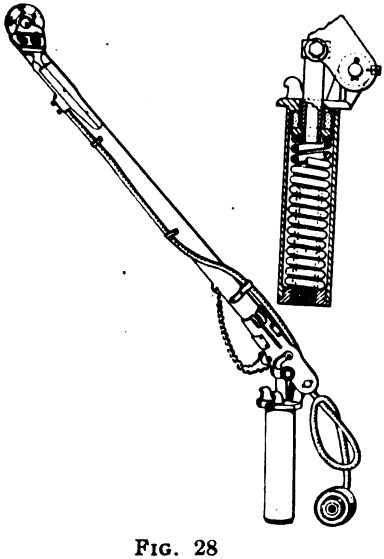

FIG. 28

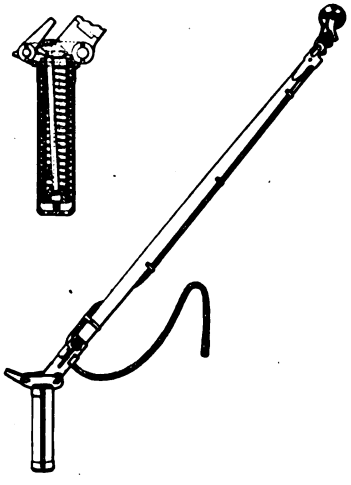

FIG. 29

manufacturers and operators could fill an evening with harrowing reminiscences of grid resistance grief.

The first controllers applied to mine locomotives were series parallel or type K controllers. The size and particularly the height of this type caused the early adoption of the rheostatic or type R controllers. The early R controllers were without means for series paralleling the motors. The reverse drum was later modified to include a series parallel switch. The next improvement was the incorporation of means to make it more difficult to buck the motors. Magnetic blowouts have been used on all these controllers.

Fig. 28 shows an early form of trolley which was widely used. This was later superseded by the trolley shown in Fig. 29. The

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principal changes which were made in this latter trolley were the smoothing out of the contact pressure curve; that is, a proportioning of the operating mechanism details, so that within the working range the pressure on the trolley wire would remain approximately constant, regardless of the height of the trolley.

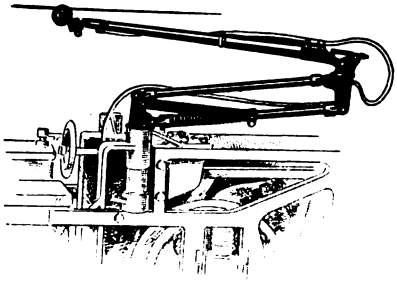

FIG. 30

The trolley was also arranged so that pressure of the wheel on the wire could be adjusted without any overhauling of the trolley.

Fig. 30 shows a form of trolley specially adapted for use with high cars where the other forms of trolley strike the car or the

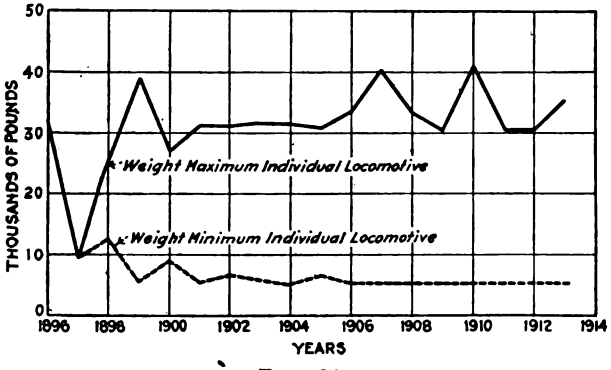


FIG. 31

coal in the car. This trolley is also adapted for use in the iron mines.

Many other detail developments could be pointed out, but it seems preferable for these to be brought out in the discussion.

The following curves show roughly the trend of the times in a few lines of development. These curves are based entirely upon

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the locomotives built by one manufacturer, but it is believed that they are fairly representative.

The curves in Fig. 31 show the maximum and minimum weight

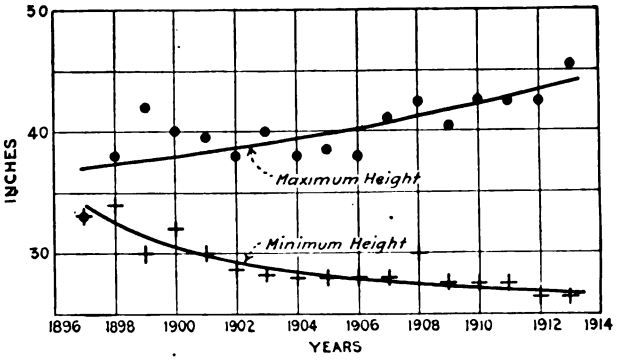


FIG. 32

in pounds for locomotives shipped each year from 1896 to 1913 inclusive.

In connection with the maximum curve, it is interesting to note that the first mine locomotive ever shipped by this particular builder is the heaviest it has ever put out. This was a

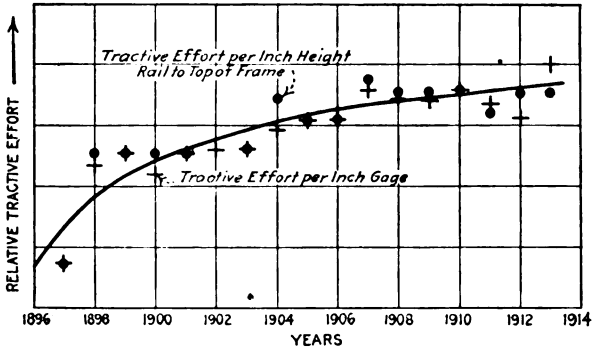


FIG. 33

three axle machine, and is therefore not included in this curve. There is no pronounced tendency of the maximum curve. In 1899 a two-axle locomotive was built, weighing approximately 40,000 lb., (18,143.7 kg.) and several of about the same weight have been built since that time. This limit has held for so long

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in coal mine service for this type of locomotive, that it seems to be pretty definitely settled.

The minimum weight locomotive has had less sharp variations. This is natural because far more locomotives of this size are required, and many are put in service every year. The minimum weight locomotive also established itself in 1899. It will be noted that improved frame constructions have in the smallest locomotives been capitalized in the shape of increased factor of safety and more powerful equipment instead of in decreased weight.

The curves in Fig. 32 show the maximum and minimum height from rail to top of frame, for each year. The maximum height curve shows a rather definite climbing tendency. If the one high spot in 1899 were absent, this tendency would be more definitely pronounced. It looks, however, logical to expect higher locomotives.

The minimum height curve is getting very close to the horizontal. It seems probable that no radical decrease is to be expected, as there is great inherent difficulty in operating these exceedingly low machines.

The curve in Fig. 33 shows in a striking manner how power has been crowded into a continually smaller space. The term power is used advisedly although the curve is based upon tractive effort, because the speeds involved in the years vary very little.

The general tendency of this curve would seem to justify the expectation of a gradual increase in tractive effort, relative to gage, while the plotted points if faired up for tractive effort relative to height, offer little hope of radical improvement with two-axle locomotives. Inherently, it is possible to double the height of the curve by using tandem locomotives. An attempt was made to show actual results with tandem machines, but so few have been made that the plotted results are jagged and show no tendency that can be profitably analyzed.

This brief discussion of the curves is offered only for what it is worth and not as a prophecy.

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*To be presented at the 294th meeting of the American Institute of Electrical Engineers, Washington, D.C., April 24-25, 1914 under the auspices of the Electrophysics Committee.*

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*(Subject to final revision for the Transactions.)*

# THEORY OF THE CORONA

BY BERGEN DAVIS

ABSTRACT OF PAPER

The theory of the corona developed in this paper explains the coronal discharge by the application of the known laws of the discharge of electricity through gases.

The experiments of Dr. Whitehead and Mr. F. W. Peek and others have shown that the surface gradient $X_s$ at the surface of a smooth wire necessary to start the corona increases very greatly as the radius of the wires decreases. As an illustration of this increase it is found that the coronal gradient $X_s$ at the surface of a wire 0.5 cm. radius is 46,000 volts per cm., while a gradient of 97,000 volts per cm. is required for a wire of 0.02 cm. radius. The phenomenon is due to ionization by impact. The ions $n_0$ move in toward the wire from the place at which they cross a region where the gradient is $X_0$ = 26,600 volts per cm. up to the wire. They produce other ions, and $n$ ions arrive at the wire. The condition for the corona is that $n$ shall be a constant. If $\alpha$ = the number of ions that one ion produces in a cm., then

$$n = n_0 e^{\int_a^b \alpha dx}$$

The $\alpha$ is a function of $X$ at every point. This function is expressed in terms of $x$. It is introduced into the above equation, and on integration the equation for the corona is obtained. The equation also contains a term for the density of the air. The equation thus takes account of changes of pressure such as altitude and temperature effects. The equation when plotted in a curve for the variation of $X_s$ with the radius of the wire, agrees with the experimental results of Whitehead and Peek with as great accuracy as the experimental results would warrant.

THE ATTENTION of the writer was first called to the coronal discharge from high-tension transmission lines by a paper presented to the American Institute of Electrical Engineers in 1911 by Prof. H. J. Ryan[1]. This discharge is a very interesting one from the point of view of the discharge of electricity through gases. The phenomena have been quite fully investigated and described by Dr. J. B. Whitehead, F. W. Peek and others.

When either a direct or an alternating high potential is applied to a smooth cylindrical conductor, there is at the surface of the wire a very high gradient of potential or electrical intensity.

1. TRANS. A. I. E. E., Vol. XXX., Jan. 1911.



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When this electrical intensity becomes great enough, the surrounding dielectric, in this case air, breaks down and a faint glow appears, and, as has been shown by Dr. Whitehead, the air becomes ionized. If the electrical intensity is still further increased, the ionization and luminosity increase also, and there is considerable loss of energy from the wire.

There are interesting relations between the surface gradient necessary to produce the corona and the radius of the wire. As the radius decreases, the electrical intensity increases very much, as is shown by the curves in Figs. 3 and 4. In a discussion of this effect Prof. Steinmetz has suggested that there is a skin-effect at the surface of a conductor; that the di-electric strength of air is altered by contact with a curved metal surface. It appeared to the writer that this could not be the case, but rather that this phenomena should be capable of explanation by the known laws of the discharge of electricity through gases. The following development of a theory of this effect appears to show that it is really a case of ionization by impact.

The theory of ionization by impact has been developed by Prof. J. S. Townsend. He has established by experiments, that if $\alpha$ is the number of new ions produced in a gas by one ion in going one centimeter when driven by an electrical intensity $X$, and $p$ is the pressure of the gas, the following functional relation holds between $\alpha$, $x$, $p$, for all values of $\alpha$, $x$ and $p$ whatsoever:

$$\frac{\alpha}{p} = f\left(\frac{X}{p}\right) \tag{1}$$

When ionization by impact takes place in a gas, the density of ionization is enormously increased as is shown by the following considerations. Let $n_0$ be the number of free negative ions crossing a unit of area of surface in a gas in unit time, under an electrical intensity $X$. Let $\alpha$ be the number of ions produced by one negative ion in going one centimeter.

If the ion moves a distance $dx$, the number produced will be $\alpha\, dx$, and if there are $N$ such ions crossing any plane, the number crossing a plane $dx$ distant will be $dN = \alpha\, Ndx$. On integrating this between $n_0$ crossing plane of start of the action, and $n$, the number crossing a plane at distance $d$ we have:

$$\frac{n}{n_0} = e^{\int_0^d \alpha\, dx} \tag{2}$$

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If the electrical intensity is uniform between $a$ and $d$, $\alpha$ is independent of $x$ and the equation becomes

$$\frac{n}{n_0} = e^{\alpha d}, \text{ which is that used by Prof. Townsend.}$$

The conditions about a cylindrical conductor may be described by use of the cross section of such conductor represented by Fig. 1.

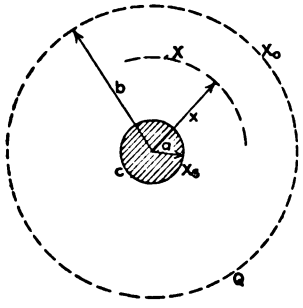


FIG. 1

The shaded portion $c$ represents the conductor whose radius is $a$. The electrical intensity at the surface of this conductor is $X_s$, and $X$ represents the electrical intensity at any point distant $x$ from the center of the conductor.

The cylindrical surface $Q$, whose radius is $b$, represents the surface where the electrical intensity has the constant value $X_0$. This electrical intensity $X_0$ is the least gradient of potential at which ionization by impact can occur. Ionization by impact and the coronal discharge itself can only take place between the surface $Q$ and the wire, in which region the electrical intensity is greater than $X_0$.

Let $E$ represent the potential difference between the wire and the ground or some other distant conductor, and let the distance of this other conductor or ground be $R$.

The electrical intensity at $x$ is:

$$X = \frac{E}{x \log \frac{R}{a}}$$

At surface it is:

$$X_s = \frac{E}{a \log \frac{R}{a}}$$

At surface $Q$ it is:

$$X_0 = \frac{E}{b \log \frac{R}{a}}$$

From the above we obtain:

$$X = X_0 \frac{b}{x}, \text{ and } X_s = X_0 \frac{b}{a}. \qquad (3)$$

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The physical process involved in the establishment of the discharge may be traced in the following way: The conductor is subject to an alternating potential. Let the maximum value of this at crest of the wave be just sufficient to produce the corona. There are a certain number of ions, $N_0$, in the region around the wire. Only negative ions ionize by impact at ordinary pressures. Suppose the wire to be at the positive phase, the $N_0$ ions move inward and when they cross the surface $X_0$ they begin to ionize by impact. They produce $N_1$ ions which approach the wire. Here some of the $N_1$ ions disappear (current loss). On the next phase, the wire is negative, these ions move outward from the wire. Some of them disappear by recombination, but there are $N_{01}$ left, and $N_{01}$ is much greater than the original $N_0$. These $N_{01}$ ions move inward on the succeeding positive phase. They produce $N_2$ ions, which on the next half phase decrease to $N_{02}$ ions, and thus the process goes on until after a number of cycles, the density of ionization about the wire at crest of positive phase is $n$. The $n_0$ in the theory here proposed is the number of ions crossing the surface $X_0$ on the phase at which the discharge appears.

Now let $n_0$ be the number crossing the surface where the intensity is $X_0$, and let $n$ be the number which reach the surface of the wire, and assume also that the visible discharge appears when $n$ reaches a fixed constant value.

From equation (**2**)

$$\frac{n}{n_0} = e^{\int_a^b \alpha\, dx} \tag{4}$$

The density of ionization at surface of conductor will increase somewhat, without ionization by impact, as the $N_0$ ions move inward. This increase will be proportional to the ratio of the radius of surface $Q$ to that of the conductor.

We may now write

$$\left(\frac{n}{n_0}\ \frac{a}{b}\right) = e^{\int_a^b \alpha\, dx} \tag{5}$$

One may assume that the discharge will appear when the ionization per unit area at the surface reaches a certain constant value $n$.

An inspection of Fig. 1, will also show that the number of $n_0$

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ions, crossing surface $Q$ per unit area, varies inversely as $b$; consequently, we may approximately assume that the whole term on the left is a constant for first appearance of discharge.

$$\text{Constant} = \left(\frac{n}{n_0} \cdot \frac{a}{b}\right) = e^{\int_a^b \alpha \, dx} \qquad (6)$$

The number of new ions $\alpha$ that one ion produces in going one centimeter is a function of $X$, by equation (**1**), and $X$ is a function of $x$ by equation (**3**) so that $\alpha$ is a function of $x$. It is necessary to express this function in order to perform the integration indicated in the right hand member of equation (**6**).

The number of ionizing impacts per cm. indicated by $\alpha$ in the right hand member of (**6**) depends upon the value of the electrical intensity $X$, which in turn depends on the distance $x$ from center of conductor (see Fig. 1). Consequently, $\alpha$ will depend upon $x$. Also, $\alpha$ depends upon the pressure of the air.

Since we find that $\alpha$ is a function of $x$ and $p$, it is necessary to express the form of this functional relation.

A few years ago, the writer[2] developed a theory of ionization by impact, by means of which the form of the function

$$\frac{a}{p} = f\left(\frac{X}{p}\right), \text{ may be expressed.}$$

The complete development of this function cannot be given here, but the reader is referred to the original paper.

The expression there obtained for $\alpha$ is

$$\alpha l = e^{-\frac{\lambda_0}{l}} + \frac{\lambda_0}{l} Ei\left(-\frac{\lambda_0}{l}\right) \qquad (7)$$

Where $\lambda_0$ is the least ionizing path of an ion when driven by a field $X$, and $l$ is the mean free path of the negative ion at the pressure considered. The least possible difference of potential through which an ion must freely run to produce ionization is $v = X\lambda_0$. The quantity $X\lambda_0$ should be a constant for any gas, independent of the pressure and independent of the electrical intensity.

2. *Physical Review*, Jan. 1907, also *Annalen der Physik, Band* 42, 1913.

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Recent experiments by Bishop[3] shows this to be the case, and the value he finds for $v$ in case of air is $v = 10.2$ volts.

Equation (7) very easily transforms into the following expression:

$$\frac{\alpha}{p} = \frac{1}{76\,L}\left[ e^{-\frac{v}{76\,L}\frac{p}{X}} + \frac{v}{76\,L}\,\frac{p}{X}\,Ei\left(-\frac{v}{76\,L}\,\frac{p}{X}\right)\right] \quad (8)$$

Where $v = X\lambda_0$, $P$ is the pressure of the air in cm. of mercury, and $L$ is the mean free path of an ion at normal pressure.

The above equation expresses the form of the function

$$\frac{\alpha}{p} = f\left(\frac{X}{p}\right).$$

If the value of $\alpha$ from this expression is introduced into equation (6), and likewise the values of $X$ in terms of $x$ are introduced from (3), we will have a complete expression for the appearance of the corona, at any pressure and for any size of conductor. However, equation (8) is not directly integrable for $x$. It contains the exponential integral

$$Ei\left(-\frac{v}{76\,L}\,\frac{p}{X}\right)$$

which is a series, every term of which would need to be separately integrated, for every case. This equation is consequently unworkable.

An integral equation which is a close approximation to (8) must be found. Equation (9) is such an expression. Its departures do not introduce any considerable errors particularly for values of $\frac{X}{p}$ less than 900.

The approximate equation is

$$\frac{\alpha}{p} = A + B\left(\frac{X}{p} - 350\right)^2 \quad (9)$$

If the constants $A$ and $B$ are given the values 0.05 and 0.0000115 respectively a good agreement of (9) to (8) is obtained as shown by the curves in Fig. 2.

3. *Physical Review*, Nov. 1911.

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By setting $X_0 = 350\ p = 26{,}600$ volts per cm., equation (**9**) becomes

$$\alpha = A\ p + B\frac{p}{p^2}\left(X - X_0\right)^2$$

Also from equation (**3**) the above becomes:

$$\alpha = A\ p + B\ p\ \frac{X_0^2}{p^2}\left(\frac{b}{x} - 1\right)^2. \qquad (10)$$

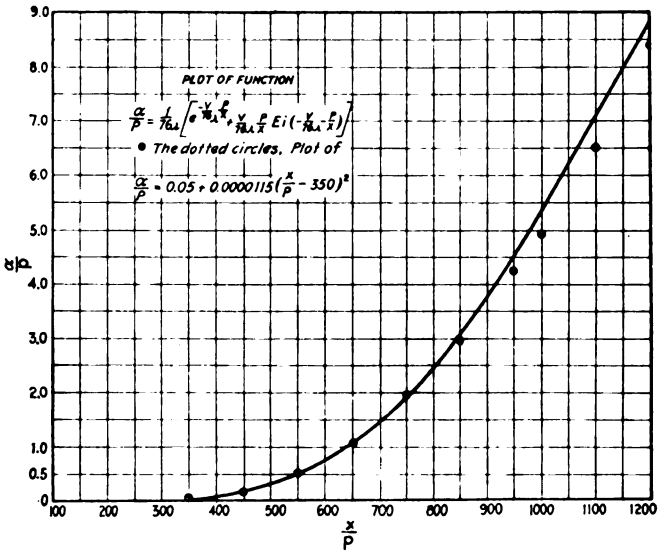


FIG. 2

It is to be noted that $X_0$ is the electrical intensity at points indicated by the dotted circle $Q$ in Fig. 1. It is the least gradient at which ionization by impact can occur. Also $X_0$ depends on the pressure is such a way that $\frac{X_0^2}{p^2} = C$ is a constant independent of the pressure. It has the numerical value $(350)^2 = 122{,}500$ volts per cm.

Equation (**10**) becomes

$$\alpha = A\ p + B\ C\ p\left(\frac{b}{x} - 1\right)^2 \qquad (11)$$

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This expression for $\alpha$ is introduced into equation (**6**)

$$\int_a^b \alpha\, dx = A\, p \int_a^b dx + B\, C\, p \int_a^b \left(\frac{b}{x} - 1\right)^2 dx$$

The limits of integration are $a$ and $b$, since the ionization takes place as the ions move inward from the surface of radius $b$ to the surface of the wire of radius $a$.

Performing the indicated integration:

$$\int_a^b \alpha\, dx = A\, p\, (b-a) + B\, C\, p \left(\frac{b^2 - a^2}{a} - 2\, b \log \frac{b}{a}\right)$$

$$= A\, p\, a \left(\frac{b}{a} - 1\right) + B\, C\, p\, a \left(\frac{b^2}{a^2} - 1 - 2\, \frac{b}{a} \log \frac{b}{a}\right)$$

Since $X_s$ is electrical intensity at distance $a$ from centre of wire, and $X_0$ is the electrical intensity at $b$ from the center

$$\frac{X_s}{X_0} = \frac{b}{a},$$

$$\int_a^b \alpha\, dx = A\, p\, a \left(\frac{X_s}{X_0} - 1\right)$$

$$+ B\, C\, p\, a \left(\frac{X_s^2}{X_0^2} - 1 - 2\, \frac{X_s}{X_0} \log \frac{X_s}{X_0}\right) \quad (12)$$

It is desirable to introduce into the above a term representing the density $\delta$ of the air, where $\delta$ = unity for $p$ = 76 cm.

Also note that $\delta\, X_0$ expresses the value of the least gradient at which ionization takes place for any density $\delta$ of the air.

Equation (**12**) now becomes:

$$\int_a^b \alpha\, dx = 76\, A\, a\, \delta \left(\frac{X_s}{\delta\, X_0} - 1\right)$$

$$+ 76\, B\, C\, a\, \delta \left(\frac{X_s^2}{\delta^2\, X_0^2} - 1 - 2\, \frac{X_s}{\delta\, X_0} \log \frac{X_s}{\delta\, X_0}\right)$$

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Upon introducing the values of the constants $A$, $B$ and $C$, equation (**6**) becomes:

$$\left(\frac{n}{n_0}\frac{a}{b}\right) = e^{3.8\,a\,\delta\left(\frac{X_s}{\delta X_0}-1\right)+107\,a\,\delta\left(\frac{X_s^2}{\delta^2 X_0^2}-1-2\frac{X_s}{\delta X_0}\log\frac{X_s}{\delta X_0}\right)} \quad (13)$$

The above is a general expression for the relation between the gradient $X_s$ and the radius $a$ of the wire for conditions necessary to produce the corona.

Writing the above in the logarithmic form, and since the left hand member is constant, setting $\log\left(\frac{n}{n_0}\frac{a}{b}\right) = K$, one obtains:

$$\frac{K}{a} = 3.8\,\delta\left(\frac{X_s}{\delta X_0}-1\right)+107\,\delta\left(\frac{X_s^2}{\delta^2 X_0^2}-1-2\frac{X_s}{\delta X_0}\log\frac{X_s}{\delta X_0}\right) \quad (14)$$

This final form may be conveniently used for comparison with experiments.

The relations between the radius of a smooth wire and the surface gradient necessary to produce the corona have been quite carefully investigated by Dr. Whitehead and F. W. Peek.

Whitehead[4] finds that equation (**15**) expresses the relation between $X_s$ and $a$ for a wire passing through the center of a surrounding cylinder.

$$X_s = 32{,}000\left(1+\frac{0.297}{\sqrt{a}}\right) \quad (15)$$

In Fig. 3 is plotted the relations of $X_s$ to $a$ as calculated from (**14**). The constant $K = 6$ is found by equating (**14**) with (**15**) for a particular value for $X_s$ and $a$.

The dotted circles represent the results of experiment as expressed by the empirical equation (**15**). The agreement between theory and experiment is very satisfactory.

F. W. Peek[5] has investigated the problem for parallel wires in the open air. He also investigated the effect of spacing of the parallel wires. He finds that if the conductors are not too near, the relations between radius and surface gradient may be expressed by

$$X_s = 29{,}800\left(1+\frac{.301}{\sqrt{a}}\right) \quad (16)$$

4. TRANS. A. I. E. E., Vol. XXX, June 1911.
5. *ibid.*

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The law of the corona for this case is the same as for a wire enclosed in a cylinder, but the electrical intensity at which it occurs is less than for the enclosed wire, as the constant outside the parenthesis has a smaller value.

The theoretical equation represents this case also. The constant $K$ has a smaller value, as the constant outside the parenthesis is (**16**) is less than that in (**15**). The comparison of theory and experiment is shown in Fig. 4. The agreement here also is very good.

## Reduction of Equation (14) to Form of Equation (15)

The fact that equations (**14**) and (**15**) plot into almost identical curves is evidence that the theoretical equation expresses

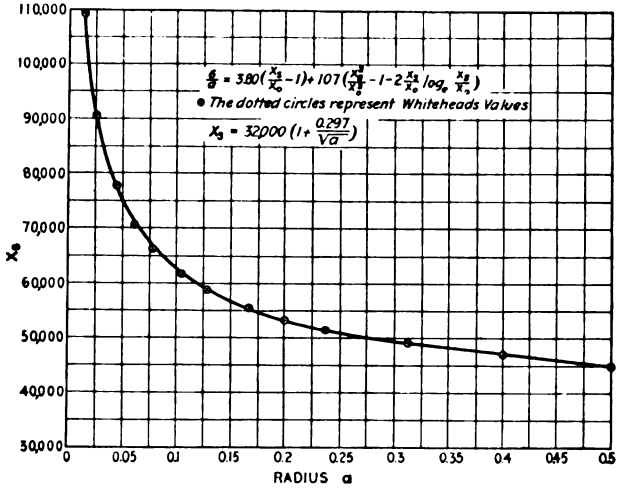


Fig. 3

the law of the corona as accurately as the empirical equations of Dr. Whitehead and Mr. Peek. However, equation (**14**) is not quite so workable in practice since it is not so simple in form and contains a logarithmic term. It is perhaps worth while to show that equation (**14**) very easily transforms into equation (**15**) if one represents the logarithmic term by a series:

$$\log_e \frac{X_s}{X_0} = C_1 \frac{X_s}{X_0} + C_2 \frac{X_0}{X_s} + C_3$$

This logarithmic term is very closely represented by the series if one gives the constants the values of 0.28,—0.82 and 0.53

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respectively. Introducing these values of $C_1$, $C_2$ and $C_3$ in the series, substituting the series for the logarithmic term of (**14**), and collecting the constants of like powers of $\frac{X_s}{X_0}$, equation( **14**) immediately changes to

$$X_s = 32{,}000\left(1 + \frac{0.297}{\sqrt{a}}\right)$$

This simple transformation makes (**14**) agree in form and value with the experimental equation of Dr. Whitehead.

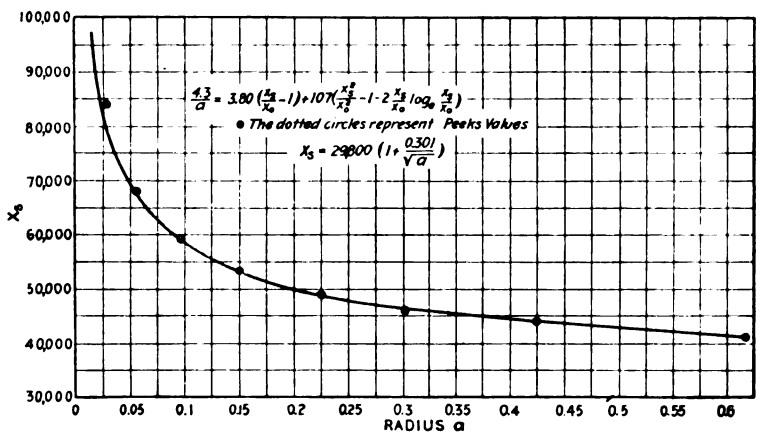


FIG. 4

## CHANGE OF DENSITY OF THE AIR

Both Dr. Whitehead and Mr. Peek have investigated the effects of pressure or density of the air on the appearance of the corona. Peek points out that both his own and Whitehead's results may be represented by the following empirical equation:

$$X_s = 31{,}000\,\delta\left(1 + \frac{0.308}{\sqrt{\delta a}}\right) \qquad (17)$$

The term $\delta$ represents the density of the air, taking $\delta$ = unity for normal atmospheric pressure and temperature. Equation (**14**) also contains $\delta$ and consequently should also express the effect of change of density.

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A plot of (**14**) is given in Fig. 5 for a few conductors of different radii, the dotted circles representing the results of experiments. Here again the agreement is very good.

## Conductors Surrounded by Cylinders, and Conductors in the Open

There is a marked increase in the surface gradient require to produce the corona with the wire surrounded by a cylinder over that of a wire in the open. The experimental values of $X_s$ are about 7 per cent greater in the one case than in the other. The theory of ionization by impact furnishes an explanation of

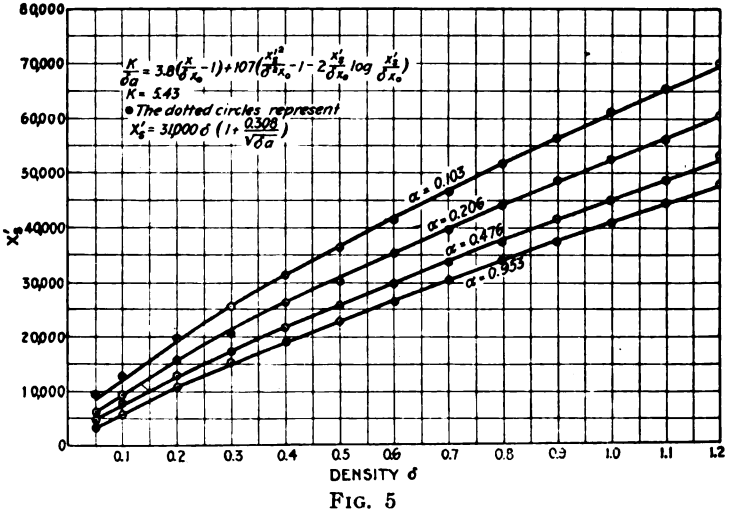


FIG. 5

this increase, as will be readily seen by a detailed study of the physical process involved in the two cases.

Consider a wire stretched through the center of a metallic cylinder, as represented in Fig. 6. The outer cylinder $M$, say, has a radius of 3 to 5 cm., these being the dimensions used by Dr. Whitehead. The central conductor is charged by an alternating potential, such that the gradient at the surface just produces the corona. The condition for the discharge is that the ionization $n$ per unit area at the surface shall reach a certain value. Assume a certain amount of ionization in the cylinder, and follow the process through a cycle. The wire is just beginning its negative phase, and as the potential rises, the negative ions

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are driven out from the wire toward the outer cylinder. If the radius $R$ is small, these ions will reach the outer cylinder $M$ and disappear before the wire changes to the positive phase. If the outer cylinder $M$ is not there, but another wire or the earth is at a considerable distance, the ions will not have disappeared, but will still exist and many will return and cross the surface $Q$, on the reversal of phase. The $n_0$ ions of equation (**13**) are thus decreased by the nearness of the cylinder, and the gradient $X_s$ is increased. One can readily calculate the change in $n_0$. For a wire in the open (see Fig. 4):

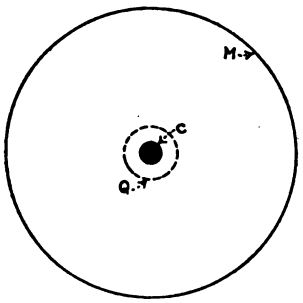

FIG. 6

$$K = \log\left(\frac{n}{n_0}\,\frac{a}{b}\right) = 4.3$$

And for a wire in a cylinder (see Fig. 3):

$$K = \log\left(\frac{n}{n_0}\,\frac{a}{b}\right) = 6$$

The ratio of $a$ to $b$ will be about the same in the two cases. It is found from the two above expressions that $n_0$ is 5.5 times as great for a wire in the open as for a wire enclosed in a cylinder.

### THE EFFECT OF SPACING OF PARALLEL CONDUCTORS

Mr. Peek has observed some interesting and unexpected results on the effect of spacing of parallel conductors. It was found that at great distances, a change in spacing had no effect on the coronal surface gradient, but when the wires were brought nearer, the gradient increased, and at a certain spacing not near enough for sparking, the gradient became nearly as great as for wires surrounded by a cylinder. As an illustration, when the two parallel conductors of 0.1 cm. radius are 20 cm. apart, the gradient is 58,000 volts per cm.; when they are 7 cm. apart, the coronal gradient is increased to 61,000 volts per cm.

These results can also be explained by the assumption that part of the $n_0$ ions disappear when the conductors are near.

Consider the physical process about conductor $C$, Fig. 7, as the

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potential goes through a cycle. The conductor $C$ begins with a negative potential which increases, decreases, and becomes positive. During the negative phase, the negative ions move outward along the lines of force towards $B$. If the conductors are sufficiently far apart, these ions will not reach $B$ before the phase changes and they are again drawn toward $C$. However, if the spacing $d$ is small enough, some of the $n_0$ ions will have reached $B$ and so will have disappeared. That is, at a certain critical spacing $n_0$ will begin to decrease, and the coronal surface gradient will begin to increase.

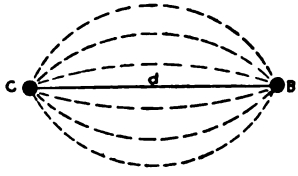

FIG. 7

This increase in $X_s$ is shown by several curves in Peek's paper. The critical spacing at which this increase in $X_s$ takes place is given in the following table ($d$ observed).

| $a$ | $X_s$ | $d$ (observed) | $d = c\sqrt{X_s a}$ |
|---|---|---|---|
| 0.103 | 58,000 | 17 to 18 cm. | 17.5 |
| 0.162 | 52,500 | 18 to 21 | 21. |
| 0.2 | 50,000 | 21 to 23 | 23. |
| 0.327 | 46,000 | 28 to 31 | 28. |
| 0.412 | 44,000 | 32 to 34 | 32. |

$c = 0.23$ = a constant.

The change in the gradient as the spacing is decreased is so gradual that the critical spacing $d$ at which $X_s$ begins to be increased cannot be sharply fixed.

The expression in the fourth column of the table for the critical spacing is derived from the following considerations: This spacing is the distance that an ion would move out from conductor $C$ in a quarter cycle. All of those ions that are to cross the surface $X_0$ at the crest of the positive wave, must be within such distance of the wire, that they can return while the potential is increasing from zero to a maximum on the positive phase.

Let $k$ be the specific velocity of an ion, and $X$ the gradient at a point $x$ at a time $t$. Then $kX$ will be the velocity at that point and time.

$$\frac{dx}{dt} = kX$$

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and $$X = X_s' \frac{a}{x}$$

also

$X_s'$ varies with the time.

$$X_s' = X_s \sin p\,t$$

$$\frac{dx}{dt} = k\,X_s \frac{a}{x} \sin p\,t$$

$$\int_a^d x\,dx = k\,X_s \frac{a}{x} \int_0^{\frac{T}{4}} \sin pt\,dt$$

$$d^2 - a^2 = \frac{k\,X_s\,a}{\pi f}$$

Since $a$ is very small compared to $d$, it may be neglected, and setting

$$c = \sqrt{\frac{k}{\pi f}} = \text{a constant}$$

the above becomes

$$d = c\sqrt{X_s\,a} \qquad (18)$$

which is the equation by which the fourth column of the table is calculated.

## The Nature of the $n_0$ Ions

The theory here proposed for the corona is founded upon the assumption, that there are a large number of ions $n_0$ which cross the surface $X_0$ and build up the ionization to $n$ ions at the surface of the wire, while the gradient is near its maximum on the positive phase.

This foundation principle seems to be opposed by some experiments of Dr. Whitehead[6]. This contradiction, however, is only apparent. It is perhaps worth while to give his work in more detail and show that this is the case.

(a) An effect was sought for by increasing the original ionization about the wire by ionizing the air about the wire within

6. Trans. A. I. E. E., Vol. XXXI, 1912.

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the cylinder by Rontgen rays. The result was negative; no change in the coronal voltage was observed.

(b) The wire is surrounded by thin paper tubes within the cylinder. "A clean copper wire 0.157 cm. in diameter, started the corona at 58.5 primary volts. This wire was then successively enclosed in thin paper tubes 2.54 cm., 1.27 cm. and 0.95 cm. diameter. These tubes were slightly longer than the outer cylinder and were insulated and held accurately concentric by means of three threads at each end".

"Ions in the region outside of these tubes would be prevented from reaching the wire, and if these ions have any influence on the coronal voltage, we should expect an elevation of this voltage, when the wire is screened as above. No change in the coronal voltage was observed when the larger tube was in place. In case of the smaller tubes the coronal voltage (primary) was lower by 1.5 to 2 volts, than when the tubes were not inserted. In this experiment, the number of ions in the neighborhood of the wire is lower when the paper tube is in place."

A closer examination of the physical process about the wire will show, however, that neither the Rontgen rays nor the paper tubes can have much effect on the number of the $n_0$ ions considered in this theory.

Suppose that the alternating potential applied to the wire for experiment (a) is such that the surface gradient will just produce the corona.

For the sake of clearness, consider that the potential is applied to the wire at the beginning of the positive phase. The ions present, due to the natural ionization of the air, move inward toward the wire, and designate by $N_0$ those that cross the surface $X_0$ at crest of positive phase. These produce ionization by impact and $N_1$ ions arrive at the wire. (see Fig. 8). These $N_1$ ions are not numerous enough, however, to produce a visible corona. Some of these $N$ ions are neutralized by the wire (current loss), and on the next phase, when the wire is negative, the remainder move outward, passing the positive ions which are moving inward. Many disappear by recombination during this time, but a number much greater than the original $N_0$ are left. On the next change to the positive phase, $N_{01}$ ions cross the surface $X_0$ at crest of wave. These produce $N_2$ ions which arrive at the surface of the wire. Part of these ions disappear as before, but leave $N_{02}$ ions for the next process. Thus the ionization builds up in a manner graph-

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ically shown in Fig. 8. The $n_0$ ions of the theory and of figure 8, are many thousand times more numerous than the original $N_0$ which are due to the natural ionization of the air.

The Rontgen rays as applied by Dr. Whitehead would increase the $N_0$ ions, but not the $n_0$ ions. But the number of cycles required to build up the ionization would be decreased by the application of the Rontgen rays.

This process requires that a number of cycles should elapse between the application of the potential to the wire and the appearance of the corona. I venture to predict that such delay would be observed if the experiment were performed in the following way. The potential of the secondary should be adjusted so as

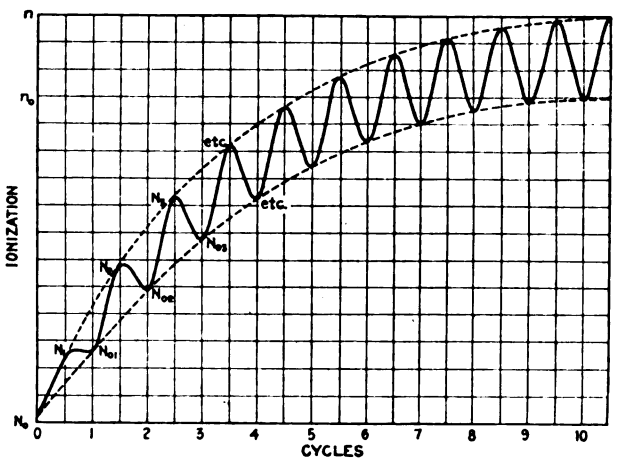


FIG. 8

to just produce the corona. A suitable switch should be placed in the secondary circuit. The current in the primary should be kept on continuously. The coronal discharge should appear many cycles after the closing of the switch in the secondary. This arrangement avoids the sudden rush of current into the transformer on closing the primary switch.

Such an effect has been observed. A graduate student, working under the direction of the writer at the Physical Laboratories of Columbia University, obtained such nice adjustment of potential difference that the discharge would regularly appear three minutes after the application of the potential to the electrodes. Here, the rate of production only slightly exceeded the

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rate of disappearance of the ions. It took a long while to build up from $N_0$ to $n$ ions.

The above view of the physical process about the wire also explains the absence of any considerable effects when the wire is inclosed in a paper tube. The building up process at successive cycles indicated in Fig. 8, goes on inside the paper tube. As the wire is on successive negative phases, the $N_{01}$, $N_{02}$, $N_{03}$ etc. ions are driven outward and cling to the inside wall of the paper tube. As the wire changes to the successive positive phases, these $N_{01}$, $N_{02}$, $N_{03}$ ions come free from the wall of the tube, and move inward, producing ionization by impact in the same way as though the paper tube had not been there.

The negative ions while on the inner wall of the tube will not produce any disturbance in the electrical intensity about the wire, because of the law that there is no electrical force inside of a hollow conductor due to a charge on its surface. The paper tube experiment which at first sight appears conclusive, really leaves the effect of the original ionization on the discharge still undetermined.

The laws governing the formation of the corona are thus fully explained by the known principles of the motion of ions and ionization by impact. The real dielectric strength of air is not altered by the curvature of the conductor. The apparent dielectric strength, however, is altered.

There is still an important problem in connection with the discharge not considered in this paper. There is a loss of energy from the conductor, which increases very rapidly as the potential is increased beyond that required to produce the corona. It would be desirable to develop a theory that would completely describe this energy loss in terms of ionization by impact. However, new and great difficulties are encountered when this is attempted. The redistribution of the ions causes a modification of the electric field about the conductor. The representation of this new field distribution in terms of the ionic charges and their motions, by a differential equation, is a matter of very great difficulty.

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(*Subject to final revision for the Transactions.*)

# SOME SIMPLE EXAMPLES OF TRANSMISSION LINE SURGES

BY W. S. FRANKLIN

ABSTRACT OF PAPER

The paper treats of the true wave phenomena which take place on a transmission line when switches are opened and closed or when a circuit breaker operates. These phenomena are practically the same in alternating- and direct-current systems for transmission lines up to say 150 or 200 mi. (240 or 320 km.) in length, and therefore the surges which are described in the paper are the surges which take place when a steady voltage is connected to the line or when the line is disconnected with a steady current flowing in it.

The details of line surging which takes place under such conditions are most easily described in terms of what may be called the " ribbon wave ", and the first part of the paper is devoted to a discussion of the ribbon wave. Then a number of practical examples are described in detail.

THE LINE surges which are described in this paper are so rapid on transmission lines of moderate length that all the details as described take place during a very small fraction of a second and any change of 60-cycle voltage or current is negligible during the very short interval of time involved. Therefore the effects which are described occur in substantially the same way in direct-current systems and in alternating-current systems.

The effects of line resistance and leakage on a line surge are extremely complicated; indeed, these effects cannot be expressed in finite algebraic terms. Usually, however, line resistance and leakage are small, and therefore a line surge on an actual transmission line approximates in its early stages the character it would have if line resistance and leakage were zero. Line resistance and leakage are assumed to be zero throughout the following discussion.

The complete solution of the differential equation of wave motion on a transmission line is involved in or expressed by the simple idea of travel[1]; and the use of this idea is exactly equiva-

1. This is by no means the case when line losses are taken into account.



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lent to the use of the general analytical solution of the differential equation of wave motion; namely:

$$y = f(x - vt) + F(x + vt) \qquad (1)$$

To solve a particular problem, the two unknown functions $f$ and $F$ must be determined so as to satisfy the given conditions which exist over the line at the beginning ($t = 0$), and so as to satisfy the conditions which are continuously impressed on the

FIG. 1

line at its ends. In this connection it must be remembered that either of the functions $f$ or $F$ may be zero or a constant, and it must also be remembered that any number of separate solutions of the differential equation of wave motion can be superposed upon each other to get a desired solution. Thus the heavy dotted line $AB$ in Fig. 17 represents a constant initial distribution of current over the transmission line; and when the end of the line in Fig. 17 is opened, a long-drawn-out wave shoots out from the

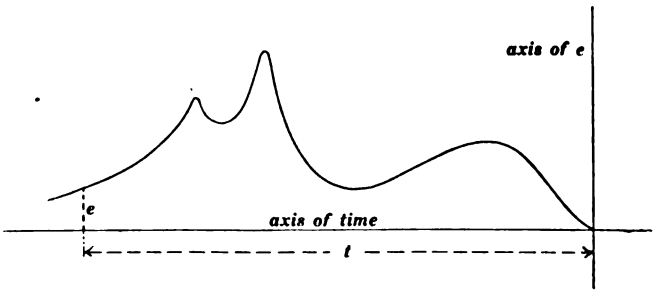


FIG. 2—SHOWING VOLTAGE $e$ OF FIG. 1 AS A FUNCTION OF THE TIME

opened end, and is repeatedly reflected at $A$ and $B$. The superposition of the initial current and any number of successive laps of the long-drawn-out wave gives the desired solution of the differential equation of wave motion.

An interesting example is to consider the effect produced when a variable voltage $e$ is applied to one end of an indefinitely long transmission line as shown in Fig. 1. The curve in Fig. 2 expresses $e$ as a known function of the time, and the wave that shoots out from $e$ in Fig, 1 is shown by the curve in Fig. 3. The

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curve in Fig. 3 evidently gives the correct solution, because in the first place the idea of travel satisfies equation (1), that is to say, the idea of travel satisfies the differential equation of wave motion; and in the second place the value of $e$ in Fig. 3 is equal to the value of $e$ in Fig. 2 at all times, that is to say, the wave in

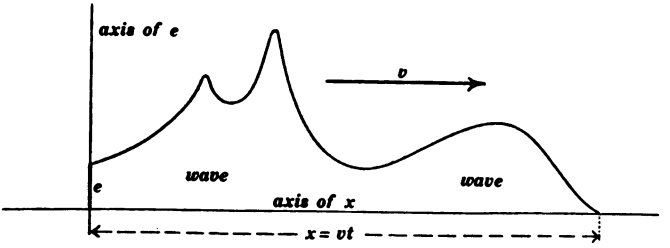


FIG. 3—SHOWING SHAPE OF WAVE WHICH SHOOTS OUT FROM $e$ IN FIG. 1

Fig. 3 satisfies the condition which is continuously impressed upon the line at the end $e$ in Fig. 1.

A clear idea of the essential details of an electromagnetic wave on a transmission line may be obtained with the help of Fig. 4. The curve $W\,W$ in the lower part of the figure represents the shape of the wave, that is to say, the ordinate $y$ represents the current

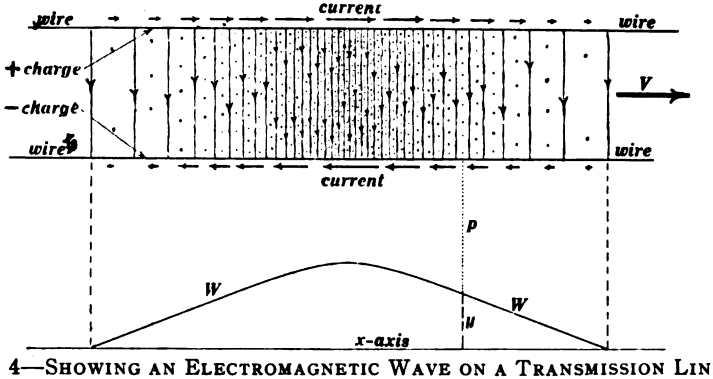


FIG. 4—SHOWING AN ELECTROMAGNETIC WAVE ON A TRANSMISSION LINE

in the wires at the point $p$ or the voltage between the wires at the point $p$, and of course the curve $W\,W$ may be of any shape whatever. The dots in Fig. 4 represent the magnetic lines of force which are perpendicular to the plane of the paper.

1. *Relation between Current and Voltage in a Pure Wave.* The differential equation of wave motion on a transmission line

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(when line losses are negligible) involves a fixed relation between voltage and current on a line in connection with a traveling wave.

This relation is

$$\frac{E}{I} = \pm\sqrt{\frac{l}{c}} \tag{2}$$

where $l$ is the inductance of the line per mile, and $c$ is the capacity of the line per mile. Hereafter the letter $a$ will be used for $\sqrt{\frac{l}{c}}$. By proper choice of algebraic signs the relation between $E$ and $I$ becomes

$$\frac{E}{I} = +a \tag{3}$$

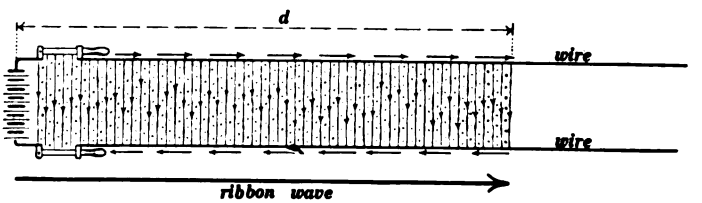


FIG. 5—SHOWING THE RIBBON WAVE WHICH SHOOTS OUT FROM A BATTERY WHICH IS SUDDENLY CONNECTED TO THE END OF THE LINE

The voltage between the line wires within the wave is everywhere equal to battery voltage $E$, and the current in each wire within the wave is equal to $E/a$.

for a wave which is traveling to the right, and

$$\frac{E}{I} = -a \tag{4}$$

for a wave which is traveling to the left.

2. *The Ribbon Wave.* Fig. 5 represents an indefinitely long transmission line to which a battery has been suddenly connected Assuming battery resistance to be negligible, the result is that battery voltage $E$ and the corresponding current $I\ (= E/a)$ is established in the line by a long-drawn-out wave which shoots out from the battery. This is a simple example of the general case which is shown in Figs, 2 and 3. If the distance $d$ in Fig. 5 is 18.6 mi. (29.93 km.), then Fig. 5 represents the state of affairs 0.0001 of a second after the closing of the switch. The long-

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drawn-out wave in Fig. 5 may be completely represented by the heavy arrow at the bottom of the figure, if it be remembered that the arrow represents the existence of a certain voltage $E$ and the corresponding current $I$ at each point along the line. In most of what follows we have to do with what are called *rectangular waves*. A rectangular wave is a wave in which the voltage has everywhere the same value $E$, and in which the current has everywhere the same value $I$.

3. *Reflection of a Rectangular Wave from the Open End of a Line.* The doubled arrow in Fig. 6 represents a wave which has been partly reflected at the open end of a transmission line. The voltage and current in the original wave are $E$ and $I$, and the voltage and current in the reflected wave are $E_r$ and $I_r$ respectively. No energy can be delivered to the end of the line, therefore voltage and current have the same values in the reflected wave as in the original wave. The direction of progression of the reflected wave being the reverse of that of the original wave requires that either voltage of current be reversed, but not both. The total voltage at the end of the line $E+E_r$ can have any value whatever, but the total current $I+I_r$ must be zero. Therefore $I_r=-I$ and $E_r=E$. *Reflection takes place with reversal of current at the open end of a transmission line.*

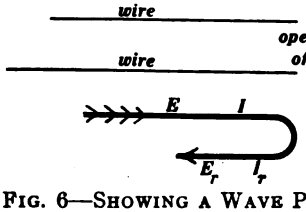


FIG. 6—SHOWING A WAVE PARTLY REFLECTED FROM THE OPENED END OF A LINE

4. *Doubling of Voltage by Reflection.* When reflection takes place with reversal of current and without reversal of voltage, it is evident that an excessive voltage is produced in the region where the reflected wave and the original wave overlap. Thus the reflection in Fig. 6 is with reversal of current so that $E_r = E$, and therefore the voltage is $2E$ in the region where the reflected wave and the original wave overlap.

A wave is reflected from an inductive receiving circuit so that $E_r = E$ at the beginning of the reflection, as explained in connection with Fig. 9. Therefore a doubled voltage is produced in this case.

This rise of voltage due to reflection is important. Thus a wave may enter an underground cable with insufficient voltage to damage the cable, but if the other end of the cable is open, or if inductive apparatus is connected across the other end of the cable, then a doubled voltage will be produced when the wave

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is reflected from the other end of the cable. If such a cable must not be subjected to more than 2000 volts, a spark-gap arrester breaking down at 1000 volts must protect the cable where it connects to an air line.

5. *Reflection of a Rectangular Wave from the Closed End of a Line.* The double arrow in Fig. 7 represents a wave which has been partly reflected from the short-circuited end of a transmission line. No energy can be delivered to the end of the line, therefore voltage and current have the same values in the reflected wave as in the original wave. The direction of progression of the reflected wave is opposite to the direction of progression of the original wave; therefore either voltage or current must be reversed, but not both. The total current at the end of the line $I + I_r$ can have any value whatever, but the total voltage $E + E_r$ must be zero.

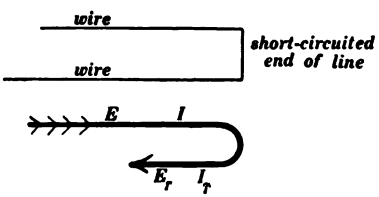


FIG. 7—SHOWING A WAVE PARTLY REFLECTED FROM THE SHORT-CIRCUITED END OF A LINE

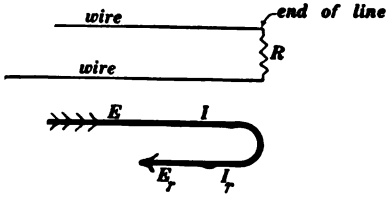


FIG. 8—SHOWING A WAVE PARTLY REFLECTED FROM A NON-INDUCTIVE RECEIVING CIRCUIT OF RESISTANCE $R$

Therefore $E_r = -E$ and $I_r = I$.

*Reflection takes place with reversal of voltage at the closed end of a transmission line.*

6. *Reflection of a Rectangular Wave from a Non-Inductive Circuit connected across the End of a Line.* The doubled arrow in Fig. 8 represents a wave partly reflected from a non-inductive circuit of which the resistance is $R$. The ratio of voltage to current must be the same in the original and in the reflected wave, except for reversal of sign, therefore

$$\frac{E}{I} = +a \tag{5}$$

and

$$\frac{E_r}{I_r} = -a \tag{6}$$

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These two equations define the original wave and the reflected wave as pure waves, the only kind which can exist if line resistance and line leakage are negligible. The total current at the end of the line in Fig. 8 is $I + I_r$, and this current flows through the receiving circuit. The total voltage across the end of the line in Fig. 8 is $E + E_r$, and this voltage acts across the receiving circuit. Therefore, since the receiving circuit is non-inductive we have

$$I + I_r = \frac{E + E_r}{R} \tag{7}$$

The original wave is supposed to be given, and the ratio $E/I$ necessarily satisfies equation (**5**). Equations (**6**) and (**7**) contain, therefore, the two unknown quantities, $E_r$ and $I_r$, and solving for these quantities we get

$$E_r = E\left(\frac{R - a}{R + a}\right) \tag{8}$$

and

$$I_r = I\left(\frac{a - R}{a + R}\right) \tag{9}$$

When $R = a$ and there is no reflected wave at all; the entire original wave is swallowed up, as it were, by the receiving circuit.

When $R$ is greater than $a$, there is partial reflection with reversal of current; thus when $R = 3a$, we get $E_r = \frac{1}{2} E$, and $I_r = -\frac{1}{2} I$.

When $R$ is less than $a$, there is partial reflection with reversal of voltage; thus when $R = \frac{1}{3} a$, we get $E_r = -\frac{1}{2} E$, and $I_r = \frac{1}{2} I$.

7. *Reflection of a Ribbon Wave from an Inductive Receiving Circuit.*[2] The solution of this problem is completely represented in Fig. 9 for the case in which $R = \frac{1}{3} a$. At the instant that the head of the ribbon wave strikes the receiving circuit the reflection is complete with reversal of current ($E_r = E$ and $I_r = -I$), because an appreciable current cannot be instantaneously established in the inductive receiving circuit. Current is, however, slowly established in the receiving circuit, and the reflected wave becomes weaker and weaker, passes through zero, and then grows stronger and stronger again, until finally we get that particular degree of steady reflection with reversal of voltage ($E_r = -\frac{1}{2} E$,

2. The analytical solution of this problem is given in Franklin's "Electric Waves," pages 99–101.

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and $I_r = \frac{1}{2} I$) which depends upon $R$ alone. The curves $cc$ in Fig. 9 are exponential curves, and the value of the exponent is $-\frac{R+a}{L} \cdot t$, where $t$ is the abscissa expressed in seconds.

8. *Transmission Line Surges which Follow the Switching on of a Generator.* A generator of negligible resistance and reactance is suddenly switched on to a line, and a ribbon wave of generator

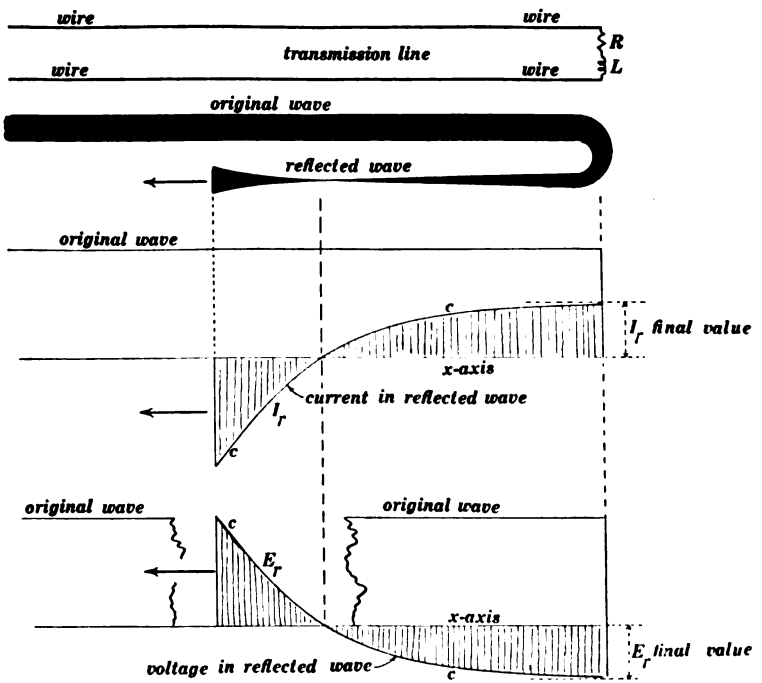


FIG. 9—SHOWING REFLECTION OF A RIBBON WAVE FROM A RECEIVING CIRCUIT OF RESISTANCE $R$ AND INDUCTANCE $L$, WHEN $R = \frac{1}{2} a$

voltage and corresponding urreent $\left(\frac{E}{I} = a\right)$ shoots out along the line. Assuming line resistance and leakage to be negligible, this ribbon wave is reflected back and forth as indicated in Fig. 10 or Fig. 11, and by adding together the voltages and currents in the successive laps, a precise knowledge of the distribution of current and voltage over the line at any instant may be obtained. Thus, after a thousandth of a second the total travel would be 186 mi. (300 km.), and by dividing this travel by the length of the line we get the number of laps of the ribbon wave, with a certain

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fraction of the next lap. By carefully reckoning up successive laps in this way complete curves can be easily plotted, showing the voltage across the line and the current in the line at any point of the line as functions of elapsed times. The ampere-time curves in Figs. 10 and 11 were obtained in this way.

The ribbon wave is reflected from the distant end of the line with reversal of current or voltage according as the distant end of the line is open or closed; and the character of the reflection of the ribbon wave at the battery end of the line is determined by

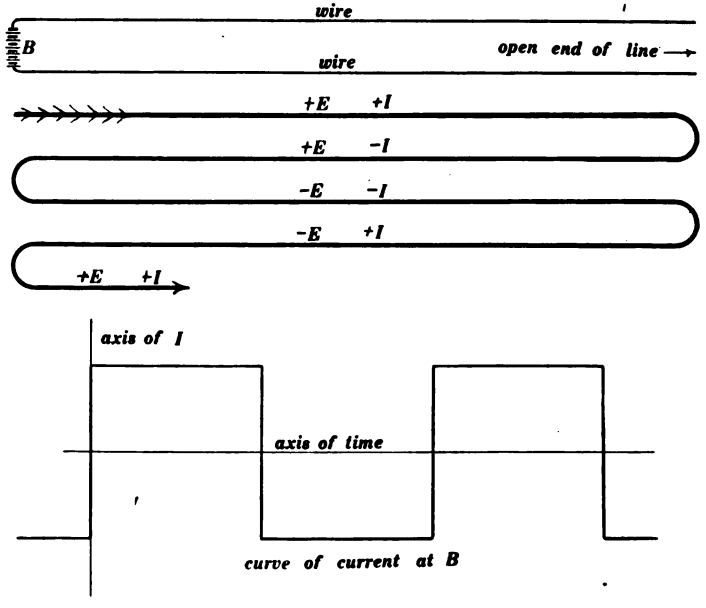


FIG. 10—SHOWING WAVE WHICH SHOOTS OUT FROM A SUDDENLY CONNECTED BATTERY, WAVE BEING REPEATEDLY REFLECTED AT BOTH ENDS OF THE LINE

the condition that the total voltage across the battery end of the line must always be equal to battery voltage.

Fig. 12 shows what happens when a generator of negligible resistance and inductance is switched on to a transmission line, a non-inductive receiving circuit being connected across the other end of the line. Fig. 12 shows the case in which $R = 3a$. In this case voltage and current are each reduced to half, and current is reversed by reflection from $R$. The character of the reflection from the battery end $B$ is determined by the same condition as in

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Figs. 10 and 11, and this reflection is complete, battery resistance being negligible.

Fig. 13 shows the growth of current at $B$ in Fig. 12 and Fig. 14 shows the growth of current at $R$ in Fig. 12 for the case in which $R = \frac{1}{3}a$. In this case voltage and current are each reduced to half, and voltage is reversed by reflection from $R$.

9. *Reflection at a Place where the Line Constants Change.* An

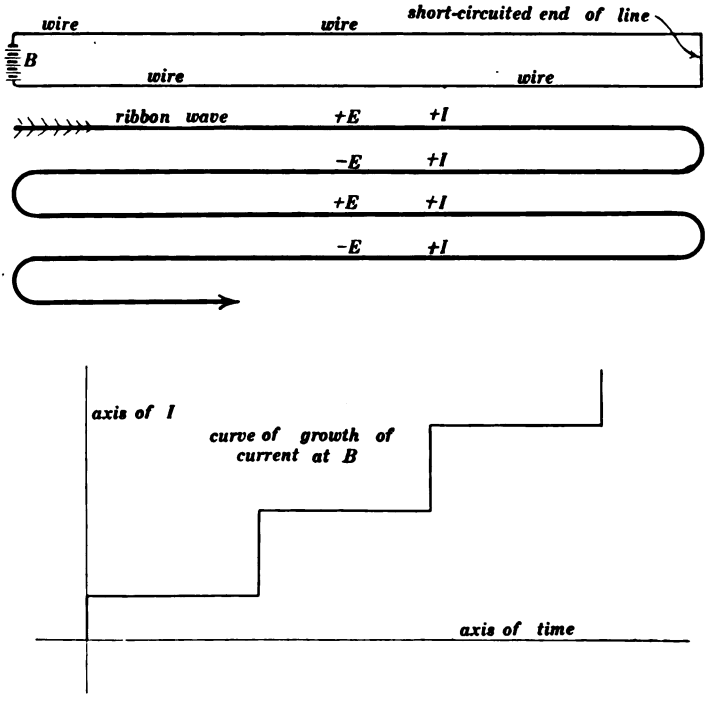


FIG. 11—SAME AS FIG. 10 EXCEPT THAT THE DISTANT END OF THE LINE IS SHORT-CIRCUITED

important case to consider is where an air line connects with an underground cable as shown in Fig. 15. A rectangular wave with voltage $E$ and current $I$ is partly turned back or reflected from the end of the cable, and partly transmitted into the cable. It is required to find the voltage and current values $E_r$ and $I_r$ in the reflected wave, and the voltage and current values $E_t$ and $I_t$ in the transmitted wave.

There are two expressions for the total voltage across the line

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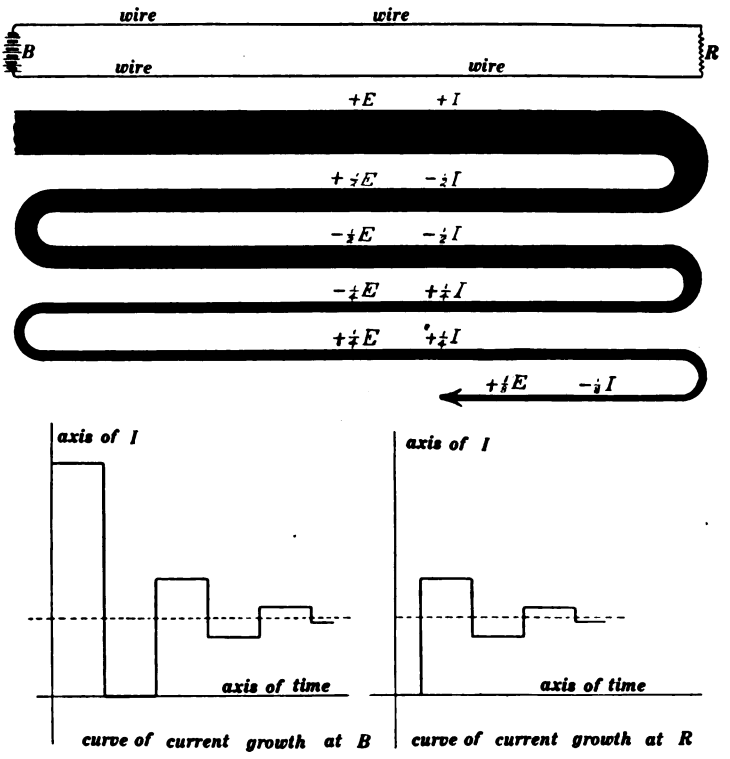


FIG. 12—SHOWING A RIBBON WAVE PARTIALLY REFLECTED AT $R$ ($= 3a$) AND COMPLETELY REFLECTED AT B

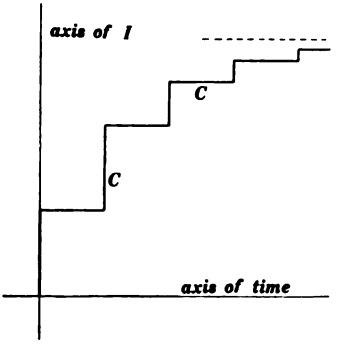


FIG. 13—SHOWING GROWTH OF CURRENT AT $B$ IN FIG. 12, WHEN $R = \frac{1}{3}a$

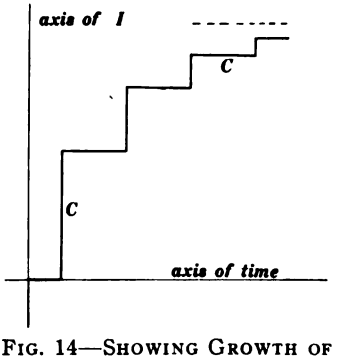


FIG. 14—SHOWING GROWTH OF CURRENT AT $R$ IN FIG. 12, WHEN $R = \frac{1}{3}a$

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at $p$, namely, $E + E_r$ on the one hand, and $E_t$ on the other hand, and these two expressions must be equal. Therefore

$$E + E_r = E_t \tag{10}$$

Also, the total current $I + I_r$ must be equal to $I_t$, so that we have

$$I + I_r = I_t \tag{11}$$

Furthermore, we have

$$\frac{E}{I} = +a \tag{12}$$

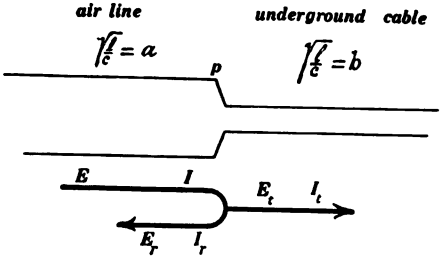


FIG. 15—SHOWING WAVE PARTLY REFLECTED AT A POINT WHERE AN AIR LINE CONNECTS WITH AN UNDERGROUND CABLE

$$\frac{E_r}{E_r} = -a \tag{13}$$

and

$$\frac{E_t}{I_t} = +b \tag{14}$$

From these equations we find

$$E_r = \frac{b-a}{b+a} \cdot E \qquad E_t = \frac{2b}{a+b} \cdot E$$

$$I_r = \frac{a-b}{a+b} \cdot I \qquad I_t = \frac{2a}{a+b} \cdot I$$

For example, a wave in which $E = 1412$ volts and $I = 2$ amperes ($a = 706$ ohms) travels along an air line, and comes to

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the end of a cable for which $b = 100$ ohms. Under these conditions $E_r = -1063$ volts, $I_r = +1.5$ amperes, $E_t = +349$ volts, and $I_t = +3.5$ amperes.

10. *Reflection at a Place where a Line Branches.* Fig.16 represents a place where a line branches into two similar lines. The doubled arrow represents a partly reflected rectangular wave, and the two transmitted waves are exactly alike because the branch lines are similar. Equating voltages across branch point, we have

$$E + E_r = E_t \tag{15}$$

Equating currents on two sides of branch point, we have

$$I + I_r = 2\,I_t \tag{16}$$

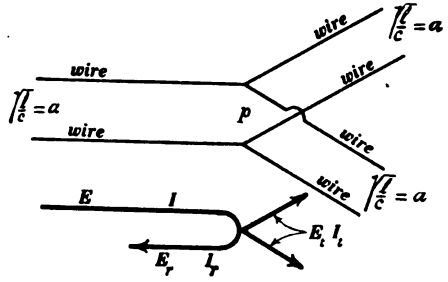


FIG. 16—SHOWING WAVE PARTLY REFLECTED AT A BRANCH POINT OF AN AIR LINE

Also, for each individual wave we have

$$\frac{E}{I} = +a \tag{17}$$

$$\frac{E_r}{I_r} = -a \tag{18}$$

$$\frac{E_t}{I_t} = +a \tag{19}$$

and from these equations we find

$$E_r = -\tfrac{1}{3}E \text{ and } I_r = +\tfrac{1}{3}I$$

and

$$E_t = \tfrac{2}{3}E \text{ and } I_t = \tfrac{2}{3}I$$

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That is, the reflected wave represents 1/9 of the energy of the original wave, and each transmitted wave represents 4/9 of the energy of the original wave.

11. *Transmission Line Surges which are Produced when a Circuit Breaker Opens.* When a circuit breaker opens, the arc which is formed persists for a very long time, relatively speaking, and the open gap in the circuit is filled with a fairly good conducting material which slowly loses its conductivity. It is about as nearly impossible to produce characteristic line surges by opening a circuit breaker as it would be to set up an abrupt water wave in a canal by allowing a cubic mile of soft mud to flow into the canal prism to stop a troublesome flow of water in the canal; and yet the moon, as a 60 cycle generator (60 cycles per month!)

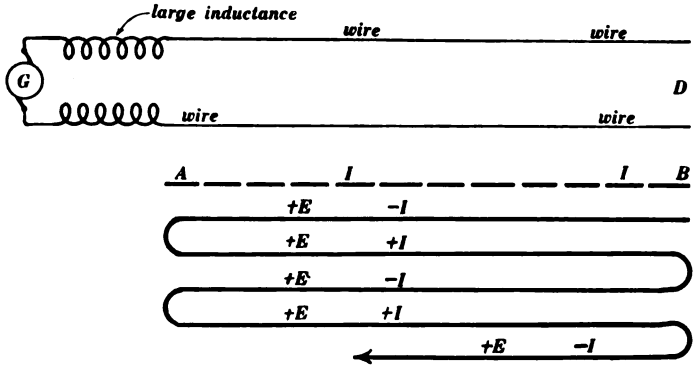


FIG. 17

The dotted line $AB$ represents the initial current in the transmission line. The long heavy arrow represents the ribbon wave which comes from $D$ after the line at $D$ is opened.

might produce a troublesome tidal wash in a large estuary while the attempt was being made to " open-circuit " the estuary in this Brobdignagian fashion! Let the reader consider this hydraulic analog carefully. It produces nearly all of the essentials of the electrical case. The conducting vapor in the arc of a circuit breaker is somewhat analogous to mud as a dam building material.

Very little need be said of characteristic line surges in connection with opening of switches, except in the case of very long lines. When a line is short, or only moderately long, what takes place may be described quite accurately in terms of the simple ideas of elementary alternating-current theory, where current values are supposed to rise and fall simultaneously throughout an entire

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circuit. The formation of a long arc between line wires in air, and the quick snapping out of such an arc, is the only case known to the writer where an electric wave disturbance can be produced by opening the circuit of a transmission line of moderate length, and the essential features of this case are shown in Fig. 17. Imagine the system to be short-circuited by an arc at the distant end $D$ of the transmission line, voltage being reduced to a negligibly small value over the whole line, and a large current $I$ established in the line. The generator is to be thought of as having a large inductance so that the generator current cannot change perceptibly during the very short time required for the characteristic line surges. When the distant end of the line is opened, a ribbon wave shoots towards the generator, is completely reflected at the generator with reversal of current, again completely reflected at the opened end $D$ of the line with reversal of current, and so on. The first lap of this ribbon wave wipes out the current in the line and lays down a certain voltage $E$ ( $= aI$). The second lap of the ribbon wave lays down a double voltage, and the original current. The third lap wipes out the current again, and lays down a voltage equal to $3E$, and so on.

It must not be imagined that the sending out of a ribbon wave depends upon a continued supply of energy at the point where the ribbon wave originates. Thus in Fig. 17 the ribbon wave is superposed upon the initial current $I$, and the first lap of the ribbon wave wipes out this current. Therefore since the current is zero, there is no energy flow at all from the opened end. The second lap of the ribbon wave lays down the original current $I$ and a doubled voltage $2E$ ( $= 2aI$), and this combination of voltages and current represents the flow of energy from the generator into the line.

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*To be presented at the 294th meeting of the American Institute of Electrical Engineers, Washington, D.C., April 24-25, 1914 under the auspices of the Electrophysics Committee.*

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*(Subject to final revision for the Transactions.)*

# SOME INVESTIGATIONS ON LIGHTNING PROTECTION FOR BUILDINGS

BY L. A. DE BLOIS

ABSTRACT OF PAPER

A description is given of investigations conducted for a large manufacturer of explosives to determine upon a suitable system of lightning protection for buildings containing explosives. The work is divided into the following sections:

(1) An analysis by oscillograph of the secondary currents induced by actual lightning discharges in vertical earthed conductors, the results seeming to indicate that such currents are non-oscillatory and aperiodic, though occurring in either a negative or positive direction. An attempt is made to explain the phenomena generally attributed to high frequency oscillations by the existence of uni-directional waves of almost vertical front.

(2) An investigation of the primary effects of a 20-in. spark in air having the same essential characteristics as those attributed to lightning when applied to a model protective system consisting of isolated vertical conductors surrounding a small building.

(3) An investigation of the secondary effects produced under the above conditions, which are considered to be static inductive rather than dynamic inductive.

A brief description is given of a general protective system recommended for explosives buildings.

IT IS the purpose of this paper to describe the results of a study made in an effort to develop a system of lightning protection for explosives manufacturing buildings and magazines which would insure at least some measure of protection, rather than a possible increase in risk—as unfortunately seems to have been the case with some so-called " protective systems." Since such systems have been based on speculative theory as to the actual character of lightning or on the behavior of model buildings when subjected to spark discharges supposed to bear close relationship to the natural phenomenon, an effort was made to obtain, if possible, some further and more dependable information, that would furnish not only a better understanding of the actual conditions to be met, but also permit more reliable reduced-scale laboratory experiments.



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## Investigation of Lightning Discharges

Secondary currents induced in vertical earthed conductors by the passage of nearby lightning discharges to earth presented themselves as a possible clue to the nature of the current in the actual discharges. Two 103-ft. (31.3-m.) wireless towers, situated on the roof of a 123-ft. (37.4-m.) office building, were utilized. The yards, 170 ft. (51.8 m.) apart, subtended a horizontal plane area of 5100 sq. ft. (469 sq. m.) represented by 21 horizontal and approximately parallel conductors. This large plane area, acting as condenser against the upper air, was found necessary in order to permit the reception of induced currents of sufficient magnitude for analysis by the instruments available. The conductors were divided into two groups of 19 and 2, to serve as " collector-aerial " and " pilot " respectively, each set being cross-connected at the ends and provided with two 180-ft. (54.8-m.) leads running obliquely downward to the laboratory on the roof. The leads were provided with horn arresters just outside the building and were connected on the inside to switches operated by ropes. This arrangement of aerials gave an excellent installation, well above the ground, with an unobstructed view of the country in all directions; thereby insuring freedom from wave-absorption by grounded conductors nearby. A ground connection was secured by a heavy cable bolted to the steel framework of the building. The natural wave length of the " collector-aerial " was found to lie between 700 and 800 meters.

The instruments used consisted of a wireless receiving equipment with various detectors, an indicating " ceraunoscope " (needle detector with electric alarm decoherer), an adjustable spark-gap, an 800-volt multicellular static voltmeter, and a double-element permanent-magnet oscillograph, modified by the addition of field coil and motor drive for the revolving mirror. The wireless equipment was used on the collector-aerial for storm prediction as described later, the " ceraunoscope " and static voltmeter between the pilot-aerials and ground to indicate respectively the occurrence of heavy discharges and the variation in static potential, the spark-gap between either aerial and ground as an alternate method of indicating the passage of discharges, and the oscillograph between the collector-aerial and ground to furnish a means for analyzing the induced currents. The low resistance, inductance and capacity factors of the latter instrument rendered it satisfactory for this purpose when the

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usual gold-leaf fuses were replaced by solid metal. Its periodic time (5000-6000) on the other hand would have been too low to permit the measurement of high frequencies, had they been encountered.

The importance of storm prediction by the wireless equipment was emphasized by the necessity of recording all the comparatively few discharges which were sufficiently heavy or sufficiently close to induce measurable currents in the aerials, a condition aggravated by the transitory nature of the storms and by their comparative infrequency. As a matter of fact, of fourteen electrical storms in the summer of 1913, only six were of a character suitable for observations, and the period during which such work could be performed averaged less than twenty minutes. It was found that after some experience with the sound produced in the wireless receivers by the waves propagated by lightning discharges, the presence of an electrical storm could be predicted from 8 to 10 hours before its possible advent, and hourly observations on their intensity would generally indicate whether it was approaching or merely passing through the field of the instruments. Assuming a rate of storm-travel of 25 to 40 miles (40.2 to 64.3 km.) per hour, it would thus seem possible to detect the presence of a travelling storm between 200 and 400 miles (321 to 643 km.) away.

Until the storm was close at hand, differences of potential between collector-aerial and the ground occurred only coincident with distant flashes of lightning, but were often sufficient to jump a small air-gap or administer a sharp shock, unless the wires were grasped firmly in the hand before the switch was closed. As soon as the edge of the storm clouds was nearly overhead, however, the aerials when disconnected from ground commenced to assume strong static charges as indicated by the static voltmeter or spark-gap. Such charges always occurred with electrical storms, though less prominently where intercloud lightning prevailed, and also often occurred with cumulus clouds that gave no other indication of their electrical character. In such cases the aerials acted as condensers of low capacity charged to high potential, and if connected to ground through the oscillograph discharged at the natural frequency of the circuit. As this was approximately 400,000 per second, while the natural period of the oscillograph was only 5000-6000, such discharges did not affect the elements, though the addition of series inductance rendered them clearly visible on the revolving

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mirror. If the spark-gap was substituted for the oscillograph at such times, sparks of discharge passed fairly uniformly for considerable periods until a lightning stroke took place, when they succeeded each other so rapidly as to resemble momentarily a single arc of some duration. At such times the static voltmeter on the " pilot " aerial departed from its usual slow swinging variation by a sudden upward swing, sometimes from zero and sometimes preceded by a gradual rise. This was generally followed by a momentary subsidence to zero.

The first attempts to use the oscillograph for indicating currents induced by lightning discharges during 1912 were not encouraging, no indications being obtained, mainly on account of insufficient capacity in the aerials, but after considerable practice with the instrument on high frequency discharges, and various modifications in the aerials and apparatus, visible indications on the revolving mirror were noted during the first storm of 1913. These were obtained only during the passage of heavy discharges comparatively close to the laboratory. With especially violent discharges the static voltmeter on the " pilot " aerial often arced over, as well as the oscillograph switches, and in several cases, the horn arresters outside the laboratory. The handling of the equipment had to be done by means of well insulated poles, or only after first disconnecting and grounding the aerials—in fact the whole work of observation was far from pleasant, especially at night, the noise of the thunder and rain being often deafening and accompanied by numerous sparks in the apparatus, and at times by sharp hissing brush discharges presumably from the building itself, and the general discomfort was increased by the possibility of interruption to the lighting service and power supply from induced effects. All these conditions naturally contributed to the difficulty of securing permanent and conclusive records.

As the collector-aerial could not be tuned to the incoming wave, and responded only with forced oscillations, great difficulty was encountered in obtaining sufficient induced currents for satisfactory indications, except in the case of unusually heavy discharges nearby. Otherwise, the photographic records were exceedingly minute and were moreover obscured by a heavy zero-line, resulting from the continuous rotation of the oscillograph film at high speed for the prolonged period necessary to insure the reception of a record—there being of course no means of foretelling the occurrence of a heavy discharge. Consequently

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visual observations on the revolving mirror were found to be more satisfactory, though of course producing no confirming records.

In August 1913 a storm of unusual duration and intensity occurred and for a time appeared to be central over the locality. Three photographic records in particular were obtained, which are reproduced in Fig. 1 as largely typical of the lesser records obtained previously.

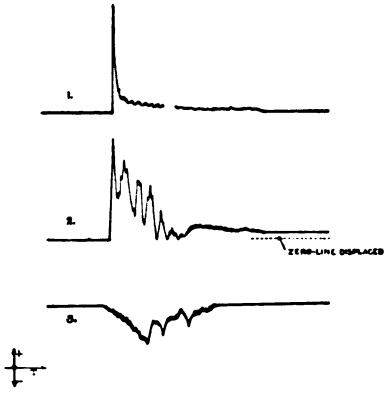


FIG. 1—LIGHTNING OSCILLOGRAMS STORM OF AUGUST 23, 1913

Referring to Fig. 1, curve (1) is a typical example of a single steep-front discharge from clouds to earth. The rate of initial rise of current is too rapid to be figured with any accuracy from the record. The maximum value of the induced current as recorded on the film was 0.5 ampere, (actually probably exceeding this amount) and the peak proper endured 0.0008 sec. The latter part of the decay of the current endured 0.02 sec., giving indications of minor sustained oscillations above the zero-line, occurring with a periodicity of about 15,000 per sec. This effect is unmistakable and, though not previously photographed, had been noted in a few of the discharges observed on the revolving mirror.

Curve (2) is a typical steep-front wave with five main and three supplementary peaks, of which the values are approximately as follows:

| | Maxima, Amperes | Duration, Seconds | Resultant Minima, Amperes |
|---|---|---|---|
| 1st Peak | 0.474 | 0.0005 | 0.225 |
| 2nd Peak | 0.387 | 0.0015 | 0.114 |
| 3rd Peak | 0.305 | 0.0016 | 0.069 |
| 4th Peak | 0.266 | 0.0014 | 0.010 |
| 5th Peak | 0.152 | 0.0012 | 0.000 |
| | Total | 0.0062 | |

These peaks are followed by a gradual rise to 0.042 amperes with indistinct indications of sustained oscillations of a higher

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periodicity than in (1) for 0.01 sec., gradually dying away to zero. The total duration of discharge was 0.0184 sec.

Curve (3) is a wave of totally different character. The direction of flow is from the earth upwards, but with a gradual rise with indications of oscillations to a maximum of 0.18 amperes which is reached in 0.0046 sec. The current then starts to decay but in 0.0023 sec. is interrupted by a sudden peak of 0.121 amperes, and again in 0.0025 sec. by another peak of 0.069 amperes. The total duration is 0.0129 sec.

A summary of all other photographic records is as follows:

| | |
|---|---|
| Total number of separate discharges recorded photographically | 50 |
| " " " " " with single peaks | 38 |
| " " " " " " multiple " | 12 |
| " " " " " " steep wave-front | 29 |
| " " " " " " sloping " " | 21 |
| Total number of strokes positive (from clouds to earth) | 43 |
| " " " negative (from earth to clouds) | 7 |

| | | |
|---|---|---|
| Average duration of 38 single peaks | 0.00065 | sec. |
| Minimum " " single peak | 0.0002 | " |
| Maximum " " " " | 0.0016 | " |
| Maximum duration of multiple discharge | 0.0034 | " |
| Maximum number of peaks in one discharge | 6 | " |

In this tabulation the three heavy discharges (1), (2) and (3) already discussed in detail are not included as their measurements were not altogether comparable with the lesser indications obtained during the previous storms. For instance, the single peaked steep-front wave (1) showed a total duration of 0.0208 sec., but of this the peak only would have been observed in the smaller records. This peak actually endured 0.0008 sec., which agrees fairly well with the average duration of 0.00065 sec. found for the 38 single peak waves, and we may assume that each of the latter may have had its own prolonged decay similar in general respects to that of (1), but which was obscured by the broad zero-line of the oscillogram.

In no records was there any indication of regular periodic high frequency oscillations in the induced current. Had they existed, the oscillograph, of which the periodic time was 5000 to 6000, would have failed to respond. This was never the case with heavy discharges to earth nearby, though it did happen, presumably for other reasons, with many purely intercloud discharges. Moreover, the static voltmeter could hardly have been expected to respond to high frequency oscillations as it did in the majority of cases of lightning discharges to earth. On the other hand, it is probable that the currents induced

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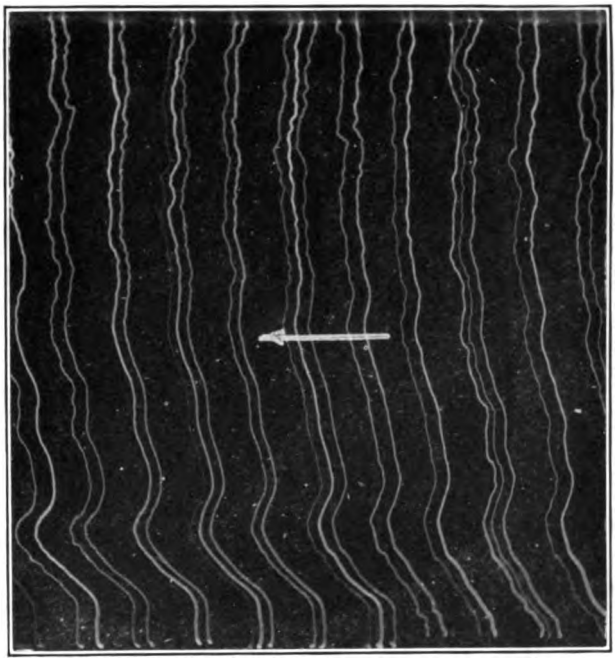
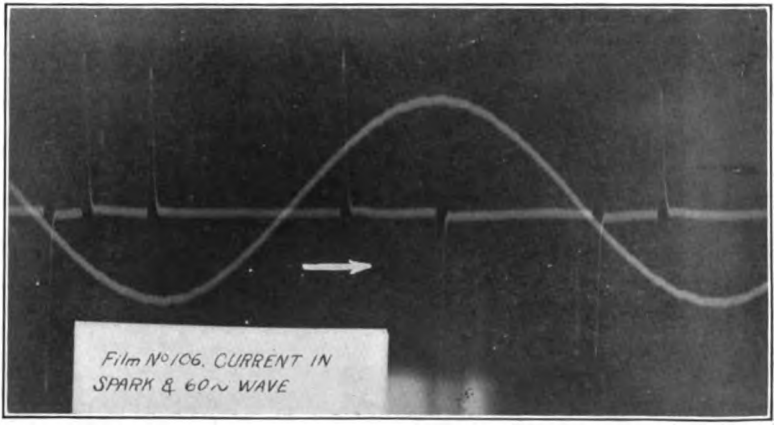


[DE BLOIS]

FIG. 2—PHOTOGRAPH OF 20-INCH SPARK WITH REVOLVING CAMERA




[DE BLOIS]

FIG. 3—OSCILLOGRAM OF CURRENT IN SPARK FROM OSCILLATION TRANSFORMER SECONDARY

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in the collector-aerial followed in a general way at least the variations in the travelling waves of the lightning discharges, since such variations, judging by the oscillograms, involved high values of $\frac{di}{dt}$ only in the case of steep-front waves, and also for the reason that the damping effect of the aerial, whose natural period of vibration was about 400,000, must have been very small. If such was the case, do not the records obtained point to the fact that lightning discharges are essentially unidirectional, non-oscillatory, aperiodic phenomena, especially since the steep wave-front occurring in the majority of such discharges would account for all the usual effects attributed to high frequency oscillations?

A point in doubt is a suitable explanation for the occurrence of multiple peaks, as in 2, and for the gradual rise of current, as in 3. In the former case, the time intervals between maxima are too short to allow the peaks to be construed as the so-called " related discharges " which are photographed as a single flash by a stationary camera, but as separate discharges along the same path by a camera slowly rotated in the horizontal plane, notably in the work of Dr. B. Walter. Since the current rarely reached zero between maxima, these peaks may represent simply the result of the " progressive break-down " of the atmosphere so clearly defined by Dr. C. P. Steinmetz, that is, of a discharge from point to point. On the other hand, the slow rise of current as in (3), may correspond to the *A* discharge of Sir Oliver Lodge, brought about by the gradual building-up of potential, possibly accompanied by the formation of brush discharges from buildings, etc., brilliant examples of which were noted in the storm during which these oscillograms were taken or by the formation of striae gradually lengthening and preparing the discharge path. If such were the case, conversely, the *B* or " overflow discharges " of Lodge might correspond to the steep-front waves. It should also be observed that the total duration of discharges as figured from the oscillograms seems greater than usually assumed on the basis of high frequency effects, and consequently the actual discharge current may be somewhat less than generally assumed on the basis of dynamic effects.

Whatever may be the true explanation of such points as these, it seems reasonable to assume that the most dangerous discharges are those with almost instant rise to maximum value, both

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on account of the impact of the stroke and the possibility of dangerous secondary effects.

## Investigation of Primary Protection

For the laboratory work a loose-coupled oscillation transformer was used with Leyden jars and rotary spark-gap, energized by a three-kw. 60-cycle magnetic leakage type transformer. Interruptions took place in the condenser circuit 527 times per sec., and a 42-in. (1.07-m.) spark of good substantial character was obtained from the secondary transformer terminals, though for practical purposes this was reduced to 20-in. (0.5-m.) during the greater part of the work. Fig. 2 shows photographs of this spark taken with a revolving camera, indicating the occurrence of groups of sparks for each half wave of the 60 cycle supply, while Fig. 3 shows on oscillogram of the current in the discharge. This consists of one main half-wave, either positive or negative, with steep-front and with an average duration of 0.00046 sec., followed by one or two suppressed half-waves. This agreement with the oscillograms of lightning discharges in the matter of steep wave-front and short duration was considered sufficient excuse for the employment of the 20-in. (0.5-m.) spark in the work to follow. It might be added that the discharge presumably corresponded to Lodge's *B* type, that is, was produced suddenly and not by a gradual building-up of potential, and in conformance with this struck equidistant ball and point electrodes impartially.

Preliminary work with this spark directed vertically downward from points (called "cloud-points") pendent from a suspended metal "cloud" to a metal ground-plate or a box of dry or moistened earth on which was placed the model of a small building constructed of pasteboard with metal roof and interior metal apparatus, pipe lines, electric lines, etc. on a scale of 1 in. to 20 ft., with four isolated vertical lightning rods placed a short distance from its corners, led to the following general conclusions, some of which are of course self-evident:

(a) The building was in the greatest danger when the discharge took place from one cloud-point placed directly above it.

(b) The lower this cloud-point, the more likely the building was to be struck, especially if the lightning rods were low or widely separated.

(c) An increase from one to four cloud-points merely increased the number of rods likely to be struck simultaneously.

(d) The closer the cloud-point to the building, the greater the number of rods which were likely to be struck simultaneously.

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(e) With one cloud-point, the farther apart the rods, the fewer were struck simultaneously.

(f) With outside lightning rods of a proper height and at a proper distance, a model similar to the one tested could be protected with apparently 100 per cent efficiency.

(g) With low or widely separated rods the introduction of a metal roof, not grounded, seemed to increase slightly the probability of the building being struck, and at the same time seemed to increase the probability of more than one rod being struck simultaneously.

(h) Grounding the roof, if the protection was poor, seemed to increase the probability of its being struck, but if the protection was good such grounding seemed to have little or no effect.

(i) The introduction of an intermediate cloud below the main cloud seemed to render one rod more likely to be struck if the intermediate cloud was high, but when low this effect was more or less neutralized.

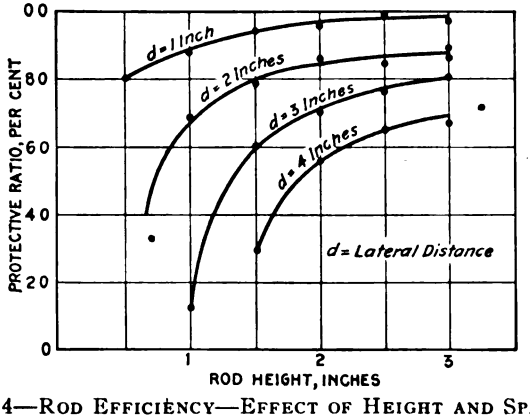


FIG. 4—ROD EFFICIENCY—EFFECT OF HEIGHT AND SPACING

(j) While a horizontal plate or a mesh screen across the tops of the rods gave perfect protection, a girdle, when the rods were too widely placed or too low, was not entirely effective.

These conclusions, though based on a length of discharge equivalent to only 700 or 800 ft. (213 or 243 m.) furnished the necessary information for the arrangement of apparatus in the following tests which will be summarized as briefly as possible and discussed in detail later.

*Protective Efficiency of Outside Rods.* Four small vertical wire rods of equal length were set up symmetrically on a metal ground-plate equidistant from a central rod which represented the object to be protected and was adjusted until its height was just sufficient to avoid being struck by any of the discharges from the cloud-point directly above. This height expressed

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as a per cent of the height of the outside rods was termed the "protective-ratio" of the latter and is plotted in Fig. 4 for a fixed cloud-point height of 20 in. (0.5 m.) above the ground-plate with varying rod-heights and lateral spacing from the central rod, and in Fig. 5 with varying cloud-point height for different combinations of rod-height and lateral spacing.

*Effect of Imperfect Grounding of Rods.* The four outside rods were raised so as to leave slight air-gaps between them and the ground-plate. This was tried for different rod-heights and air-gaps, but the effect on the protective ratio was almost exactly equivalent to that produced by cutting off from the tops of the rods an amount equal to the length of the air-gap.

*Effect of Conductivity of Rods.* A long series of tests was

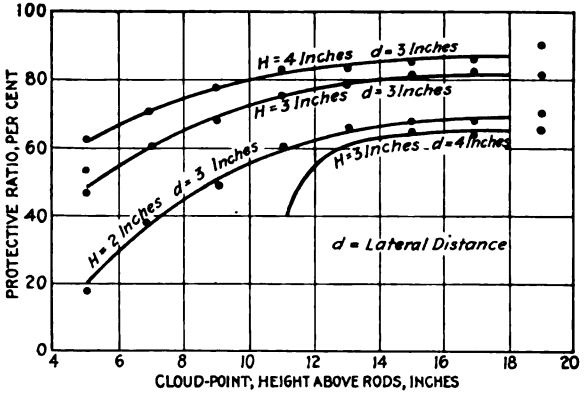


FIG. 5—ROD EFFICIENCY—EFFECT OF CLOUD-HEIGHT

made with rods of different materials, of different diameters, and with rods in which were inserted small inductances. The protective-ratio of good conductors such as wires of different metals of various diameters were almost identical and even the insertion of inductance with and without iron in the magnetic circuit did not seriously affect their efficiency. Poor conductors, however, such as green and dry wood, wood moistened with water, acids, etc., or rendered partially conducting by a lead pencil mark or by a carbonized streak resulting from a previous discharge, though frequently struck, failed to consistently protect any low object in their vicinity—even the ground-plate itself. Also, in contradistinction to good conductors, when struck they arced over for their entire length,

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wood being splintered and eventually ignited after the moisture and volatiles had been driven off or consumed.

*Discussion of Results.* The function of a lightning rod is presumably two-fold:

(1) To form a projection from the surface on which the lower charge resides, extending sufficiently above the objects to be protected and thus present to the clouds a salient point having the same relative potential as the lower surface.

(2) When struck to carry off the current of discharge without potential differences in its length sufficient to cause the discharge to split off or be diverted to nearby objects.

As regards the first function, it is evident that the rods, in order to maintain the same potential as the lower surface must be of conducting material and should be preferably in direct electrical contact with that surface. Their conductivity and potential relation should be such as to permit their following sudden, in fact, precipitous variations in the potential of the lower surface and therefore should not involve any appreciable time-element, as might be the case if high inductance or capacity were introduced. Aside from this, a high degree of conductivity would seem unnecessary. Poor conductors, on the other hand, such as dry wood, green wood, or wood with small wetted perimeter, though they might be struck in the natural course of events and the discharge follow along their surface in preference to a path of higher resistance through the air, would show no consistent protective-ratio, as was the case in the tests on different materials and as seems to obtain in nature for trees.

In order to fulfill the second function, high conductivity with low inductance seems imperative, though where isolated rods could be used the effect of lateral spacing should be considered; thus if the distance from rod to building was as great as the height of the rod, it would seem that a rod of the minimum resistance to resist fusing could be used.

As regards protective-ratio, it seems probable that the rods are nothing more than shunt-paths for the building and its interior equipment. If the latter is in direct contact with the lower surface of charge the rods should also be in such contact or should be increased in height somewhat more than the equivalent distance. Theoretically the former seems preferable as one would be led to believe that rods not in direct contact with the lower surface, though of good conductivity, might under some circumstances lag behind the changes in potential of the lower surface and so suffer a loss in efficiency, though

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this was not borne out by the tests on the effect of imperfect grounding. On the other hand, it is uncertain exactly what the lower surface of charge is. It is presumably not the earth's surface unless wet; it may be the surface of permanent moisture, though well authenticated cases of discharges passing down mines, deep wells, etc. seem to point to the existence of even lower charges; in any case it is probably of good conductivity as there seems to be no evidence of " interearth "—corresponding to intercloud—discharges.

The curves for protective-ratio tend towards a constant value independent of cloud-height, seeming to indicate that only the lowest part of the path of discharge is affected by the rods. The geometrical relation between the length of the discharge path from the cloud-point to the building and from the cloud-point to the rods is given by the formula

$$H_r = \frac{d \tan a}{2} + H_b$$

where $H_r$ = height of rod in feet.
$H_b$ = height of building in feet.
$d$ = lateral distance from highest point of building to rods, in feet.
$a$ = angle subtended from cloud-point by rod and highest point of building.

This obtains only for small values of ($a$) but was found to agree with the experimental results by the addition of a constant $K = 0.11$, making the formula

$$H_r = d\left(\frac{K + \tan a}{2}\right) + H_b$$

It seems applicable to the condition of four rods surrounding a building where $d =$ or $< H_r$. It should be noted that it involves no factor for cloud-height other than in the angle ($a$) and therefore indicates that the results of laboratory tests on protective-ratio, etc. might be applicable to natural conditions if the scale of reduction was observed.

*Probability of Being Struck.* To test the efficacy of the usual argument that lightning rods " attract " lightning and so increase indirectly the danger to the building, a long series of tests were performed directly to scale, on a basis of a minimum length of lightning discharge of 3000 ft. (914 m.) in mountain-

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ous districts. Very small models of the building selected (48 by 32 by 41 ft. or 14.6 by 9.7 by 12.4 m. actual) were placed centrally on a cardboard target representing a circular area of 600 ft. (182.8 m.) radius, and this on a somewhat larger ground-plate with cloud-point directly above. The " probability-of-being-struck " was considered to be the number of discharges that fell entirely or in part on the building, lightning rods or within the area subtended by the latter and was expressed as a percentage of the total strokes falling within the 600-ft. (182.8-m.) radius.

Summarizing the results, it would seem that the erection of a building of non-metallic construction of the size in question without contents increased the danger to the plane area only slightly (4 per cent)—until the building was wet, when the " probability-of-being struck " was increased 32 per cent (net). If a metallic building was erected instead, the " probability-of-being-struck " was increased 58 per cent or if the building was grounded 62 per cent. When metal apparatus was installed in a non-metallic building the " probability-of-being-struck " was increased 12 per cent to 50 per cent depending on the height of the apparatus, and if the apparatus was grounded 26 per cent was added in the case of the lower equipment but apparently nothing in the case of the higher equipment. On the other hand, the addition of a short metal ventilator to the grounded apparatus increased the " probability-of-being-struck " 30 per cent more.

When a metal roof was added to a non-metallic building containing metal apparatus the " probability-of-being struck " increased only slightly, whether the building was wet or dry, but when this roof was grounded the " probability-of-being-struck " was increased 12 per cent to 56 per cent, depending (inversely) on the height of the grounded metal apparatus inside.

With a non-metallic building with non-grounded metal apparatus and four outside lightning rods 70 ft. (21.3 m.) high and located about 50 ft. (15.2 m.) from the corners of the building, the " probability-of-being-struck " was increased 38 per cent to 54 per cent, depending on whether the building was wet or dry. With a grounded metal roof installed, the " probability-of-being-struck " was increased only 12 per cent, and if the metal ventilator were installed the net increase in " probability-of-being-struck " would probably have been even less.

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It is these latter conditions that are of particular interest in determining how much the danger from lightning to the building in question which was of non-metallic construction was increased by the erection of rods and apparently in this case the rods " attracted " about 10 per cent to 50 per cent more strokes. On the other hand, if the building had had a metal roof, if it were equipped with metal apparatus reaching nearly to the top, or if its exterior were wet with rain, the effect of the rods would be to add very little to the " probability-of-being-struck. " Moreover, it should be noted that these tests were made not only under the conditions of an isolated building on a plane area, but also with the cloud-point directly about the building—a combination very unlikely to occur in nature.

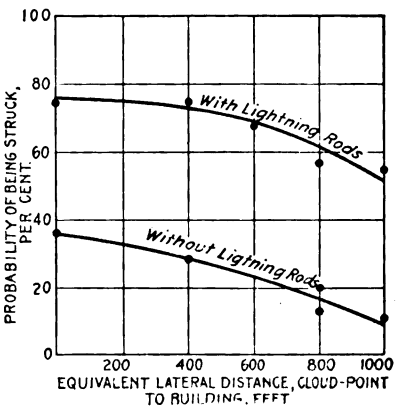


FIG. 6—PROBABILITY OF BEING STRUCK—EFFECT OF CLOUD DISPLACEMENT.

The effect of the position of the cloud-point is shown in Fig. 6 in which the " probability-of-being-struck " is plotted against the horizontal distance from cloud-point to building.

## INVESTIGATION OF SECONDARY EFFECTS

In order to reproduce secondary effects in a model building on a scale sufficiently large to be visible, an arbitrary standard of 1 in. (2.54 cm.) to 2 ft. (60.9 cm.) was adopted. This allowed the use of a model of sufficient size to permit the construction of interior apparatus with reasonable accuracy of detail and, though the relative length of cloud discharge was diminished in proportion, it was felt that this, while increasing the intensity of static inductive effects, would not affect dynamic inductive

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effects, since in any event the upper part of a vertical discharge would have little influence because of the narrow angle subtended by it. On the other hand, for dynamic inductive effects it was desirable to have the current of discharge as great as possible and the factor $\frac{di}{dt}$ as high as that of lightning.

The model building was constructed of wood with one side open and was completely equipped with metal apparatus, including pipe-lines, electric lines, etc. extending for some distance outside, all metallic parts being separately removable and practicable to interconnect and ground. It was placed directly on an extensive ground-plate with the metal " cloud " above. Secondary discharges were noted by eye or by the use of a small exploring spark-gap.

*Static Inductive Effects.* Tests were made without direct discharge other than brush from the cloud. Secondary brush and spark discharges were noted inside the building and the following somewhat obvious general conclusions were reached:

(a) All conducting surfaces not thoroughly grounded, when exposed to the influence of a charged cloud immediately overhead, acquire a potential against ground which increases with the height of the conducting surface above ground.

(b) A difference of potential will exist between all conducting surfaces not bearing the same average spacial relation in the electrostatic field to ground or to nearby grounded objects. Such average spacial relation is determined by their shape and size as well as distance from ground or grounded objects.

(c) Conducting surfaces in a vertical plane which would acquire practically no potential from their position in the electrostatic field may acquire a charge from the influence of adjacent objects.

(d) The grounding of a conducting surface generally increases the danger of sparks from adjacent non-grounded surfaces.

(e) Interconnecting adjacent conducting surfaces can prevent differences of potential between them but may increase the tendency of the lowest surface (relative to ground) to arc to ground.

(f) Discharges tend to take the shortest path, and large surfaces in the horizontal plane should be interconnected or grounded at more than one point.

(g) A grounded roof acts as shield for objects beneath it and even when poorly grounded diminishes the potential between them, but potentials can be introduced below it by conductors which extend inward from the outside, provided they are of sufficient capacity.

(h) Secondary discharges may occur from the sudden charge of an overhead cloud or from its discharge. The discharge in any case follows the natural frequency of the circuit and consequently may become oscillatory, though this condition is improbable in the ordinary interior apparatus, excepting only electrical equipment.

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(i) The effect of adjacent lightning rods is to diminish the intensity of secondary effects, though for outside rods of reasonable height and spacing, the "secondary static protective-ratio" is practically inconsiderable.

*Dynamic Inductive Effects.* Tests for such effects were made both with the discharge from the secondary of the oscillation transformer and with the primary current of the latter carried down a vertical rod close to the model building. In the latter case the current was calculated to be approximately equivalent to a lightning discharge of over 100,000 amperes maximum value with a half-wave duration of approximately 0.000005 sec. —a condition far more severe than any indicated by the oscillograph storm-records. In no case could dynamic inductive sparks be obtained, though occasional static sparks were produced in unbalanced partially closed loops. This failure was attributed to the comparatively small area of the partially closed loops formed by the various equipment and by the fact that neither these loops nor vertical conductors could be "tuned" to the magnetic waves and consequently responded only with forced oscillations. When it is considered that with a high aerial of large capacity such as described in the first part of this paper, currents of only a fraction of an ampere were obtained with comparatively nearby discharges, it does not seem unreasonable that the dynamic inductive effects in a small model building should be insignificant as compared with the static inductive effects.

## General Recommendations for Protective Systems

As a result of this work, the general recommendations for the protection of manufacturing and storage buildings where such protection is justified either by the impracticability of the operators always leaving the building during a storm, or by the value of the building or the character of its contents, consisted in a series of vertical isolated rods of iron pipe placed outside and surrounding the buildings, and grounded to annular conductors buried in the earth at least as low as the water pipes, with extensions running out radially at the corners; metallic roof projections such as ventilators to be eliminated as far as possible; metallic roof and floor coverings to be grounded at their salient angles; overhead pipe-lines and other metal conductors to be grounded at intervals and also where crossing the annular conductor; lightning arresters for outside electric lines and also for the lowest points of the building wiring (to remove

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static charges); complete interconnection and grounding of all metal objects in the interior.

This paper has been prepared for the purpose of stimulating discussion and further investigation along similar lines, rather than for the advancement of any new theories. Others, for example, Sir Oliver Lodge and Prof. Elihu Thomson, have already pointed out that lightning discharges may be non-oscillatory and yet produce all the effects that seem to have led to the assumption that they are oscillatory in character. As for the laboratory investigations, both on primary and induced effects, it is recognized that these could have resulted in further and more certain conclusions had they been pursued with the aid of larger apparatus—such as is probably readily available to others, and to these the hope is expressed that they may become further interested in the investigation both of lightning discharges and of sparks produced artifically in the laboratory, as well as their interrelation with its bearing on the protection of buildings.

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*To be presented at the 293d Meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 9-10, 1914, under the auspices of the Committee on Use of Electricity in Mines.*

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# MINE DUTY CONTROLLERS

BY HARRISON P. REED

ABSTRACT OF PAPER

The paper is devoted to discussion of the advisable types of control to be used for various mining equipment, particularly in bituminous coal mines. Complexity and theoretical details have been eliminated as far as practicable with the idea of impressing on the reader the need for certain definite features, without going into the theoretical details of these features.

Electric controllers for equipment outside of the mine proper as a rule have to meet different operating conditions than those controllers which are installed underground. The operating conditions are taken up in detail and proper control equipment is suggested to meet these conditions.

The object of the paper is to bring out clearly to the mine operatives the fact that suitable control equipment is just as important as the installation of a suitable motor, and moreover that no motor, however well adapted to the service, will stand up properly if it is not operated with a controller designed and built specifically to meet the existing installation and operating conditions.

THE application of the electric motor to bituminous coal mines has developed so rapidly that there is no section of the industry in which the motor has not been installed. Not only is the application universal, but the use of electricity in coal mines is steadily increasing, principally due to the increased cost of producing steam at the colleries.

The design of satisfactory motor and control equipment for coal mines is a considerable problem, because of the severe operating conditions encountered. The class of attendants, usually employed by the mines to maintain electric motors and their accessories, is unskilled, principally because of the location of the mines and the conditions of work. Many changes in help take place for the same reasons, and it is, therefore, difficult to train the attendants and make experts of them. These conditions make it essential that rugged and reliable electrical equipment be installed.

As the use of electricity in the mines has increased, the electric motor for operating mining machinery has been developed much



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more rapidly than suitable controlling devices. Only within the past few years have those concerned realized that the selection of a proper controller is as important as the selection of a suitable motor. Too often is the controller given secondary consideration with the result that a good motor may appear to disadvantage, simply because it is not operated with the right control equipment.

At coal mines, motors are used for haulage, hoisting, ventilating, pumping, coal-cutting, tipple or breaker power, drilling, washing, machine shop and blacksmith shop. In the design of electrical equipment for mines, it is necessary to carefully consider the following: explosive dust and gases, continuity of operation, voltage fluctuations and dampness. It is, of course, advisable to install the control apparatus in a locality which is unaffected by sparks or short circuits tending to some derangement of the apparatus. The design, however, must be made so as to minimize leaks to ground, short circuits, etc., which may cause ignition of explosives, mine gases or of coal dust, with disastrous results. In gaseous mines, arc producers such as circuit breakers, switches and sliding contacts of rheostats must be properly protected, either by breaking the arcs in oil, or by providing explosion-proof cases.

On account of the unskilled attendants in the mines, the electrical equipment receives less than the usual amount of intelligent attention, while on account of the conditions of operation, it should receive more. Much is therefore left to the designing engineer to solve, but on the other hand, much could be done to improve conditions by the employment of a supervising electrical engineer at an attractive salary, whose duty it would be to *see* that better attention is paid to the care and maintenance of the electrical apparatus.

From a safety standpoint, and it is the writer's understanding that we are to follow the slogan " Safety First ", the mine ventilating fan is the most important power-driven machine used within the mining district. Absolute continuity of service is necessary during mining operations to remove poisonous and explosive gases and coal dust from the underground workings. Mine fans are not usually installed within the mines, but at the mouths of the shafts. Mine fan service is, perhaps, the hardest duty possible for a commutator type motor. It runs continually at a constant load, and the mere fact that the load is constant prevents the motor from running light and allowing the brushes to polish the commutator.

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## Fan Motor Control

It is still a debateable question as to whether constant or variable speed mine fan motors should be used. Some claim that the fans should be arranged to operate at a peripheral speed of maximum efficiency. This means constant speed; but nearly everyone agrees that variable speed is practically necessary on the mine fan except for tunnels, subways and old workings. Opinions differ as to whether it is better to use mechanical or electrical means to vary the speed of the fan. Mechanical speed changing devices, such as Reeves variable speed drive are used, but the tendency is towards obtaining the speed changes electrically, especially when this can be done economically. Speed control of a direct-current motor is easily and economically accomplished by shunt field regulation. The speed control of an alternating current motor is quite a different problem. A straight slip-ring induction motor with control by resistance in circuit with the secondary is perhaps the most familiar type in this country, but it is open to serious objection because of the rheostatic losses with resultant low efficiency. The commutating-pole slip ring motor is used but very little on account of the complexity of construction, which arises from the necessity of commutating both primary and secondary windings. The commutating-pole squirrel cage machine is more simple, but hardly suitable because of its starting characteristics. It is most advisable from a safety and economic standpoint to have the motor self-starting after it shuts down due to failure of voltage. With a squirrel cage motor, this is difficult to accomplish because of the flywheel load.

The Sherbius system is one which is used extensively abroad, but the writer understands it has not come into use yet in this country. This system consists of a motor-generator set impressing an adjustable frequency lower than the line frequency on the rotor of the fan motor. This system is exceptionally efficient where the speed reduction is not great. The motor-generator set must have a capacity equal, in percentage of the fan motor capacity, to the speed reduction desired. Thus if 25 per cent speed reduction is required, the motor generator set must have 25 per cent of the capacity of the fan motor. When a speed below normal is wanted, the motor generator set is used. while when normal speed is desired, the secondary of the main motor is short circuited after starting. With the Sherbius method of speed control, the losses are minimized and the efficiency is high.

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On account of the possibility of frequent failures of line voltage there must be an attendant continually employed in the fan house or a self-starting controller must be installed. The automatic self-starter should be designed so as to permit the operating speed to be set by a proper authority. When the voltage again comes on the line, after failure, the controller should of itself cause the motor to start and resume the speed it was operating at when the voltage failed. This control has been accomplished very effectually for direct current motors. The starter is automatic and is governed by a simple snap switch. The starting operation is governed by a pilot solenoid and the shunt field is automatically weakened to an amount corresponding to the setting of the field rheostat lever. An example of this type of control is shown in Fig. 1. The speed-setting field rheostat is shown on the center left hand side of the board. The controller is equipped with a voltage relay so arranged that when the voltage drops below a predetermined value, the relay drops its plunger, thereby opening a circuit causing all of the starting resistance to be inserted in the armature circuit. The motor then runs at a reduced speed until the voltage again becomes normal, when the voltage relay establishes a control circuit which causes the starting resistance to be cut out, again allowing the motor to run at the proper maximum speed. The reason for re-inserting the starting resistance on low voltage is to guard against "flashovers" at the motor brushes, when the voltage suddenly jumps back to normal. An overload relay is also provided and is especially recommended for shunt wound motors. This is connected to momentarily open the motor circuit and prevent "flashovers" when the line voltage falls abruptly and the motor tends to feed into the line. With compound-wound motors, the overload relay is not essential because the series winding weakens the field when the motor acts as a generator. All of these complications in control could be avoided by the installation of separate feeders for the fan motor, or lines of such capacity as would minimize voltage fluctuations, and it is questionable whether the more or less complicated control is justified under these conditions.

Since moisture and dirt are so prevalent in the locality of coal mines, both the control panel and grid resistance are treated with a special moisture-repelling and insulating compound, corrosive bearings are eliminated and all parts necessarily made of iron or steel are enameled or copper plated.

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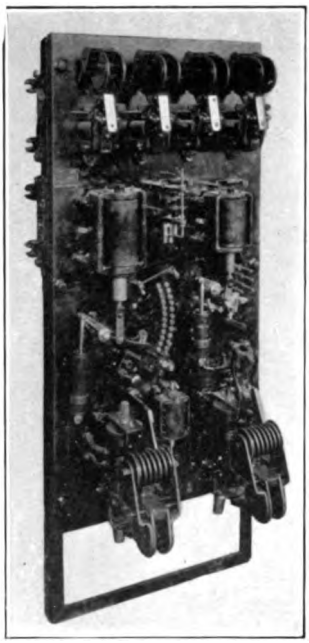

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FIG. 1

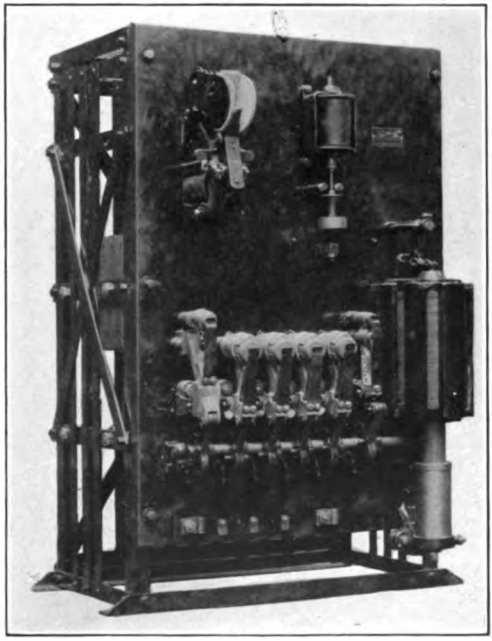

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FIG. 2

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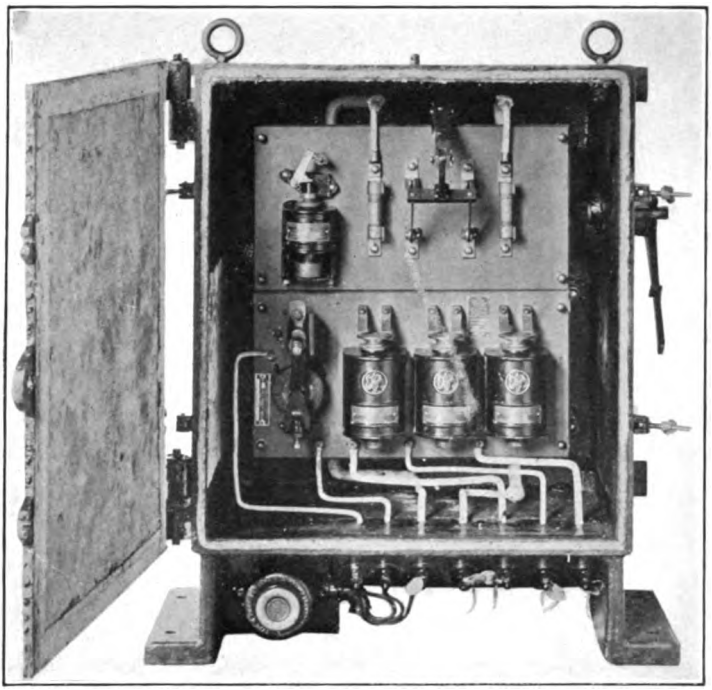

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FIG. 3

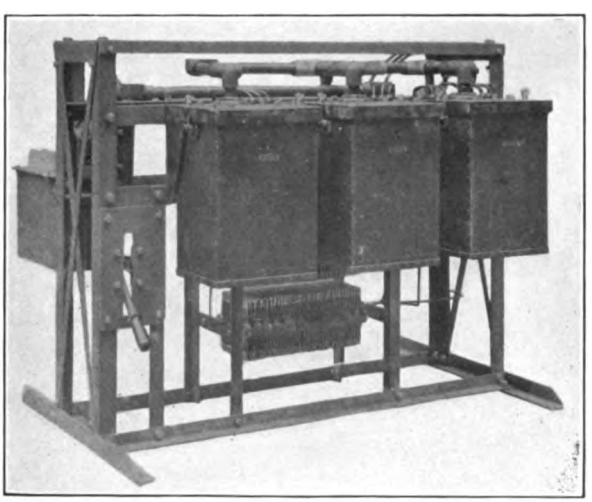

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FIG. 4

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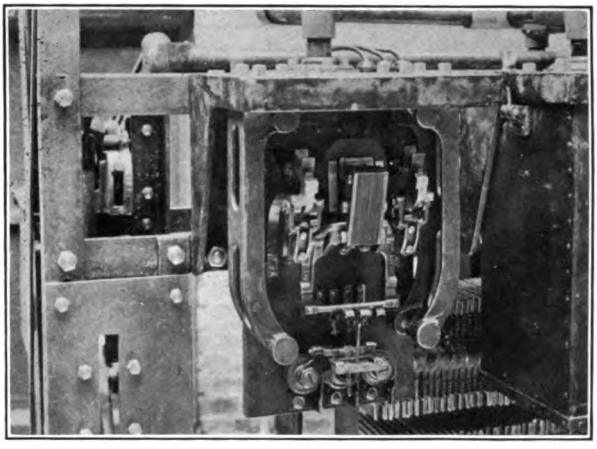

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FIG. 5

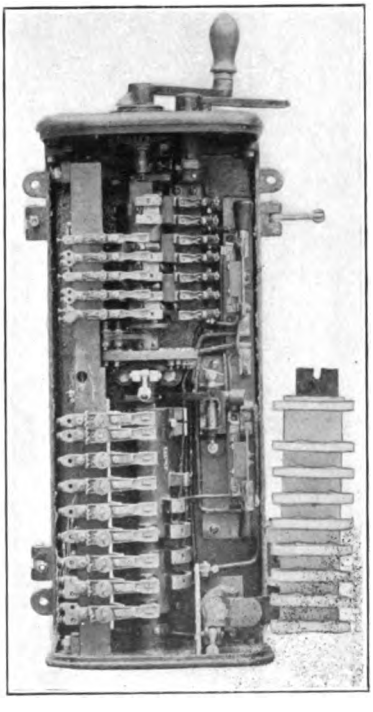

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FIG. 6

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## Pump Motor Control

Mine pumps are generally installed directly within the mine, because otherwise the suction head would be prohibitive. The pumps are usually of small capacity and should be operated by a self-starter with a float switch in the sump, or arranged to run continuously. The starter should be designed for automatic acceleration of the pump on resumption after failure of line voltage.

Generally speaking these pumps are placed some distance from the mine workings and therefore explosion proof motors and controllers are unnecessary, but it is difficult to design electrical apparatus which will stand up under severe moisture conditions prevalent. A typical pump motor starter for direct current arranged with a voltage relay for protection of the motor against severe voltage fluctuations, is shown in Fig. 2. The starter is specially designed to guard against corrosion and electrical leakages by using non-corrosive metals and by liberal application of an insulating varnish which helps to prevent short circuits as well as to keep moisture from the iron parts necessarily present for magnetic purposes.

An encased, moisture proof starter is shown in Fig. 3. This is an equipment especially adapted to installations within the mine, even in locations where arcing is dangerous, because it is equipped with a cast iron case, the cover of which is clamped down on a soft gasket, making the case air tight. The leads are connected to terminals and a special trough is cast in the enclosing box in which is poured a sealing compound covering the junction of the leads and the terminals. At the right-hand side of the box, facing it, is a handle which closes and opens the service switch. The acceleration of the motor is accomplished by limiting the current peaks with series wound switches.

It might be well to mention here the rather interesting alternating-current controller shown in Fig. 4. This is a 125-h.p. 2200-volt, three-phase, 60-cycle automatic starter for a slip ring motor. The starter is " explosion proof " and is mentioned for this reason. The switches are magnetically operated and the circuits are made and broken under oil. The interior of one of the oil switches is shown in Fig. 5. This controller was installed in the Homestake Mining Co.'s gold mine at Lead, S. D. The outfit starts a pump automatically from a float switch. The control circuit is stepped down to 220 volts so that the float switch does not have to handle the high voltage.

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## Locomotive Controllers

A subject which is occupying much thought among coal mining engineers is the mine locomotive. The tendency is to eliminate the overhead trolley where there are low ceilings. This may be done either by the use of a trailing cable, kept taut by a tension reel, or by the use of storage battery locomotives. The trailing cable was not very popular until the automatic motor-driven cable take-up was developed. Without this device the dragging cable was always in the way. The motor driving the cable take-up is connected across the line in series with a step of resistance. When the cable is to be hauled in, the motor winds it up, and when paying out is required the cable overhauls the motor.

On account of the difficulties attending the use of trailing cables, it would seem that the coming mine locomotive, when not in main entries, will be operated from a storage battery carried on the locomotive. The present trouble with storage battery locomotives is the necessity of laying them up for charging or of having two sets of batteries and charging them at intervals. The battery must be carefully watched and attended. If the batteries could be automatically charged without delay, the usefulness and reliability of the storage battery locomotive would be materially increased. This may be accomplished by the use of an automatic reverse current cutout, so arranged that when the locomotive picks up the trolley, the battery will be automatically put on charge. If, however, the line voltage is for any reason lower than the battery voltage, the battery will be automatically cut off from the line. The same applies when the line voltage fails, so that the battery will not be discharged into the line. In this way the same locomotives may be used for gathering and hauling trips. This will result in the battery frequently receiving a boosting charge. The nickel-iron battery, which seems the most popular for mine locomotive work will show its maximum efficiency when so charged.

Manually operated drum controllers are almost universally used for mine locomotives. These are usually of the series parallel type and there are two prevailing styles, each of which has its advocates. The first operates the same as a standard street railway drum which has two levers, one reverse and one for accelerating. The other style also has two levers as above, but the reverse lever has two positions each side of the "off" position, one for motors in series and the other for motors in

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parallel. This latter scheme is advantageous because it is easier to get straight series only, during gathering.

Rheostatic drum type control is sometimes used for underground haulage engines. A typical drum controller for this service is shown in Fig. 6.

For slope mines, the winding drum for haulage is generally installed in the tipple and whole trips of cars are hauled up at once. These winding or mine haulage machines are usually alternating-current motor-driven with secondary control, either by means of a secondary resistance drum or by means of a liquid rheostat. It is sometimes advantageous to be able to change gears for pulling strings of cars in from the sidings. There has been a tendency of late to put in safety cut-offs so that the current to the motor is interrupted before the cars get to the top. Variable inertia plays an important part in the stopping point, and in fact, the variable stopping point sometimes becomes so annoying that a flyball-governor limit switch in addition to the ordinary limit switch is installed, so connected that if the speed is high the governor allows the first limit switch to trip. If the speed is low, the first limit switch is " shunted " by the governor and the haulage may continue until the second limit switch is engaged.

## Hoist Control

A straight vertical hoist is used to a limited extent. Almost invariably this type of hoist can be best electrified by the use of the variable-voltage system, because the hoists are short and therefore acceleration is an important consideration. A flywheel is used to store the energy for acceleration. Even with this arrangement, electrification is in many cases of questionable economic value.

A diagram of an equalizer hoisting set is shown in Fig. 7. The hoist is driven by a shunt-wound, direct-current motor, the motor receiving its energy from a motor-driven generator. The motor-generator set has a heavy flywheel which absorbs energy when the load falls below a certain value and gives up energy when the load is above this value. The speed and direction of rotation is governed by changing the field of the generator. When the generator field is weakened while the motor is in operation, the motor operates as a generator and the generator as a motor, thus delivering energy to the flywheel and giving a dynamic braking effect on the hoisting mechanism. Where an alternating-current motor is used to drive the generator, the liquid rheostat

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gives very good regulation. The three phases of the rotor are connected to three stationary plates in separate earthenware pots. Above the stationary plates are connected together three movable plates. These are nearly balanced by an adjustable counterweight, the movement of which is controlled by a small induction motor. The small motor receives its energy from series transformers in the main line of the large induction motor and thus the current in the two motors is proportional.

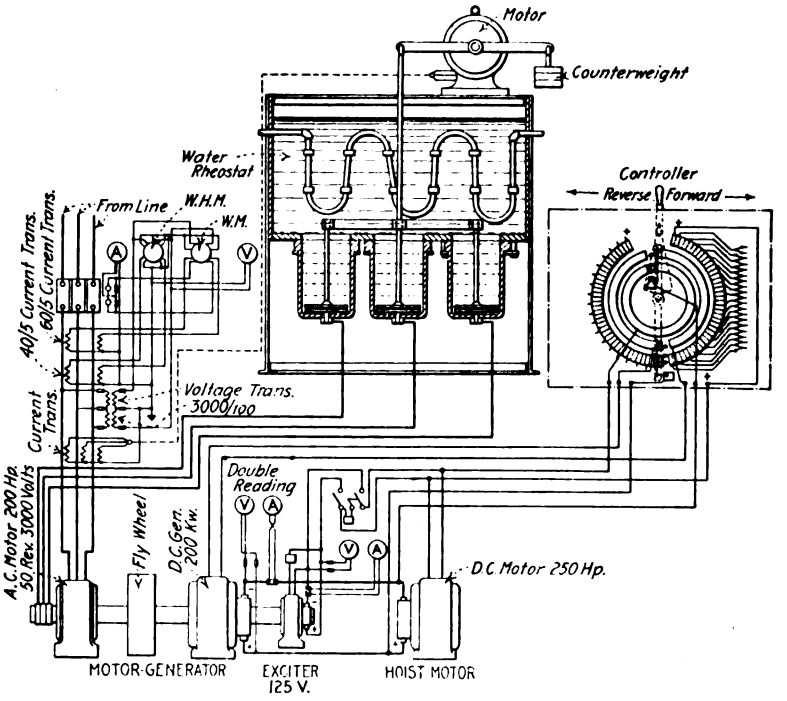


FIG. 7

If the main motor takes more current than it should (depending on the adjustment) the small motor takes more current and raises the counterweight, thereby separating the plates of the liquid rheostat and increasing the resistance in the rotor circuit. This decreases the speed and permits the flywheel to give up some of its stored energy

One case where the efficiency of a vertical hoist was greatly increased by the use of electricity is shown by a change made at the Berwind White Company's mine at Windber, Pa. It was

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found impracticable to change the shaft to take care of a larger elevator with more sidings for loading, and an increased capacity of the hoist was necessary because of the increasing production in the mine. A magazine hoist was installed, having a cage with four decks. These decks are loaded by a similar auxiliary cage within the mine. The loading cage is operated by an electric motor and controlled by a simple master switch, so that each of the four decks are brought in succession to the level of the track in the main entry. After the loading cage is full, the cars are run onto corresponding decks of the main magazine hoist and are lifted out of the mine.

## Machine Control

Coal cutting machines are controlled by a plain hand starter fully enclosed. The simpler and more substantial this starter, the better. There is a tendency to design motors for coal cutting which may be thrown directly across the line to start. The writer believes this is a step in the proper direction, because then the control may take the form of a simple hand switch, preferably oil immersed.

The control of an electric punch, or drill is usually a straight hand starter and the more simple this is the better.

An important consideration in mine electrical appurtenances is the terminal box. This is used wherever a motor has trailing cables and should be so arranged that putting the plug in the box will close the circuit in oil. An overload should be supplied, which when it trips, will throw the plug out.

To sum up the situation, mine controllers are just as important as the motors themselves and the control equipment should receive more thoughtful consideration if our electrical mine installations are to prove successful.

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*To be presented at the 294th meeting of the American Institute of Electrical Engineers, Washington, D.C., April 24-25, 1914 under the Auspices of the Electrophysics Committee.*

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*(Subject to final revision for the Transactions.)*

# SOLENOIDS

BY CHARLES R. UNDERHILL

ABSTRACT OF PAPER

Maxwell's law for the attraction between the halves of a bar electromagnet is not correct for electromagnets of the plunger type with air gaps between the cores because the flux in the cores is, to a large extent, independent of the reluctance in the air gap on account of the magnetic leakage from the inner end of either core back to the other end of the same core.

In this paper, only the characteristics of direct-current electromagnets are discussed. An attempt is made to show the correct law of attraction for tractive electromagnets and to calculate the value of the magnetizing force at any point along the axis of any solenoid. Test characteristics are given to support the theories.

The work done by an electromagnet of the plunger type in closing its air gap is largely proportional to the length of the air gap, although, when the reluctance of the air gap and the total m.m.f. are of low value, the law of Carichoff is approximately correct for the total attraction.

THE EXTENSIVE use of electromagnets of the plunger type has caused the details of their design to become increasingly important. They are frequently divided into two classes; viz. long-range and short range. The equations in common use for calculating the static pulls due to short-range electromagnets, while more or less satisfactory for relatively short air-gaps, since the pulls are usually greater than calculated, are not applicable for predetermining the pulls when the air gaps are relatively long. In this paper, the static pull is always meant.

A general equation is desirable, by means of which the pulls may be predetermined for any type of movable-core electromagnet, whether or not it is provided with either a frame or stop, or both. Such an equation would be applicable to electromagnets designed to operate on either alternating or direct currents, after the mean effective values of the m. m. fs. which produce the pull had been determined at points throughout the range of travel of the plunger. The shapes of the mean effective pull curves for alternating-current electromagnets would naturally differ from those for direct current, owing to the different values of the m.m.fs. at corresponding points throughout the range of



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travel, but the general law for the mean effective pull for a given m.m.f. would be the same in both cases, after making corrections for iron losses*

In this paper, only the characteristics of direct-current electromagnets are discussed. The voltage across the windings and the current strength are assumed to be at constant value, in any given case, and the plungers are assumed to be at rest; so that it is not necessary to consider the effects of self-induction which are in evidence in alternating-current electromagnets and also in those operating on direct current when the plunger is in motion.

The fundamental equation of Maxwell,

$$P_s = \frac{B^2}{8\pi} \tag{1}$$

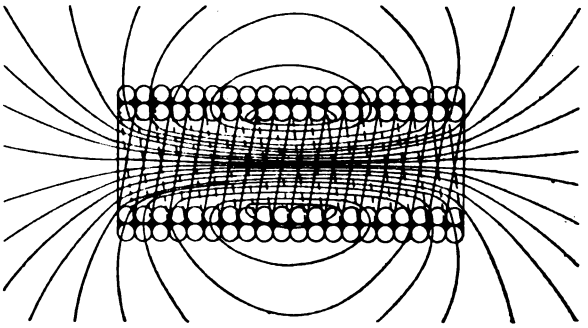

FIG 2. —MAGNETIC FIELD OF SOLENOID

for the attraction in dynes per sq. cm. does not apply, either directly or tacitly, to the case of a solenoid-and-plunger only, or to plunger electromagnets with relatively long air gaps.

The familar analysis of Maxwell's equation is here given. The magnetic induction $B$ consists of two components, $4\pi I$ ($I$ being the intensity of magnetization in the iron) and the magnetizing force $H$. Hence

$$B = 4\pi I + H. \tag{2}$$

Substituting (2) in (1),

$$P_s = 2\pi I^2 + I H + \frac{H^2}{8\pi}, \tag{3}$$

*See "Alternating-Current Electromagnets," *Electrical World*, Vol. 63 No. 5, p. 260 (1914).

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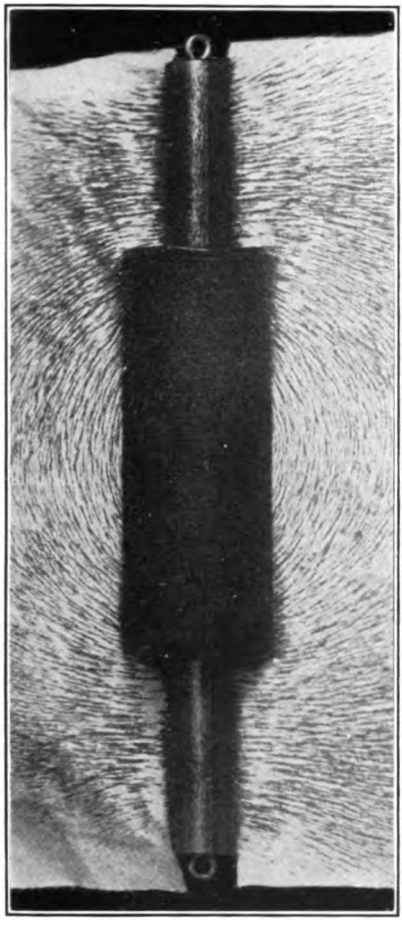
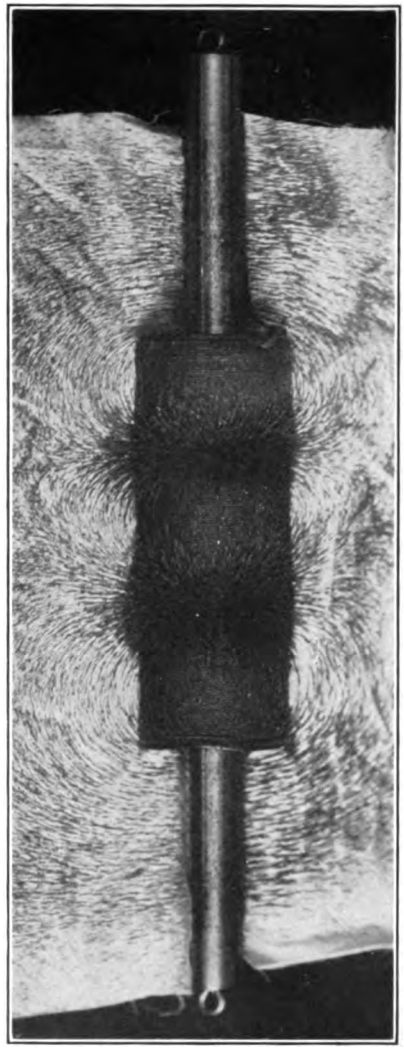


[UNDERHILL]

FIG. 1—MAGNETIC FIELD OF BAR ELECTROMAGNET WITHOUT INTERNAL AIR-GAP



[UNDERHILL]

FIG. 5—MAGNETIC FIELDS WHEN AIR-GAP IS INTRODUCED

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which is the equation for the attraction in dynes per sq. cm. between the two halves of a bar electromagnet separated at its middle at right angles to the axis of the core, but perfectly joined magnetically; hence there is assumed to be no leakage from the

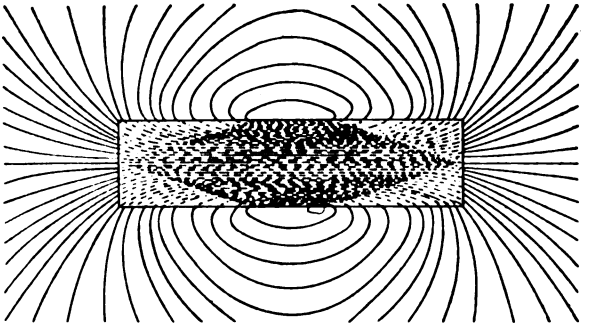

FIG. 3—FIELD OF BAR PERMANENT MAGNET

ends of the abutting half-cores back to the opposite end of the same half-core, as shown in Fig. 1.

Conventionally stated, the attraction between the ends of the iron half-cores is $2\pi I^2$; $IH$ is the attaction between the half-coil

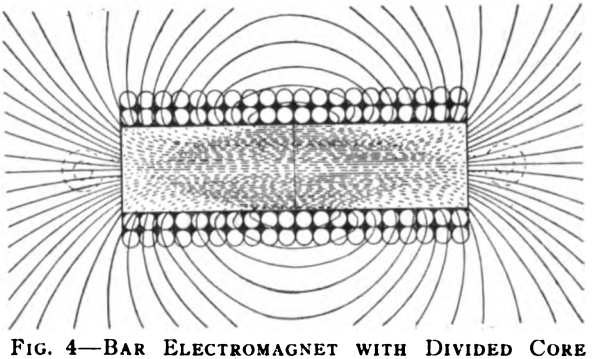

FIG. 4—BAR ELECTROMAGNET WITH DIVIDED CORE

and half-cores, and $\frac{H^2}{8\pi}$ is the attraction between the half-coils which is not available in a single coil as commonly used in practise and is, therefore, neglected.

In Figs. 2 and 3 are shown the fields of a solenoid and a bar permanent magnet respectively. The following assumptions apply to Fig. 4, which shows the field of a practical bar electro-

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magnet: The core is cut across at the middle but the joint is as perfect magnetically as though the structure was solid; the coil is uniformly wound in layers; the complete core fits closely inside of the coil, but either half can be moved, without friction, along the horizontal axis of the coil.

When spring balances are attached to the protruding ends of the half-cores, and the coil "floats" around the complete core, the pull required to separate the two half-cores is $2\pi I^2+IH$, since the coil is not divided. Now, as soon as the two half-cores are separated, Maxwell's law no longer holds because what before was a single electromagnet has now become the equivalent of three electromagnets. This is clearly shown in Fig. 5. Each half-core now has a field like that of the permanent magnet in Fig. 3, and the air gap has a similar magnetic field. The total m.m.f. is now divided into three components, so far as the conditions inside of the core of the coil are concerned, and this is the

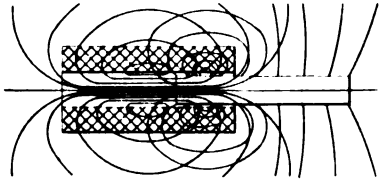

FIG. 6—PLUNGER ONE-THIRD IN SOLENOID

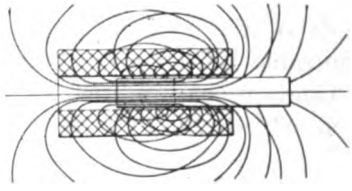

FIG. 7—PLUNGER TWO-THIRDS IN SOLENOID

basis of the doctrine of the effects of magnetic leakage in electromagnets of the plunger type, which is of great importance in continuous-current electromagnets but of paramount importance in alternating-current electromagnets.

Figs. 6 and 7 show the conditions which exist when a single core or plunger is inserted different distances within the coil. The density of the flux within the solenoid is assumed to be always the same at a given point, and is greatest at the middle of the coil along the horizontal axis. The position of maximum structural flux density of the plunger is always, approximately at least, half way between the inserted end of the plunger and the end of the coil at which the plunger enters. This is apparent in Fig. 5. When the middle of the plunger is at the middle of the coil, the two magnetic fields coincide and force is required to move the plunger in either direction.

When two plungers are placed within the solenoid, as in Figs.

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5 and 8; spring balances are attached to the protruding ends, and the balances moved in the direction of the arrows, with the coil " floating " on the plungers, the pull as measured on either balance is the total pull which can be obtained with either plunger, since one pull is active and the other is reactive. The coil merely acts as a connecting link between the plungers. There is, how-

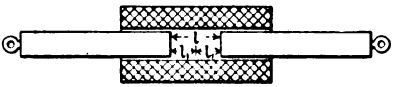

FIG. 8—SOLENOID WITH TWO PLUNGERS

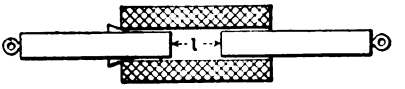

FIG. 9—SOLENOID WITH ONE PLUNGER FIXED IN POSITION

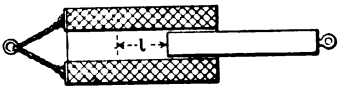

FIG. 10—ONE OF THE PLUNGERS IS OMITTED

ever, some attraction between the ends of the plungers, but this is slight when the air gap is so long. Therefore, omitting the attraction between the inner ends of the plungers, it makes no difference whether the conditions are as in Fig. 8; in Fig. 9, wherein one plunger is rigidly fastened to the coil, or as in Fig. 10. wherein one of the plungers is omitted entirely.

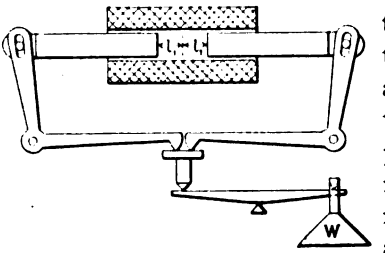


FIG. 11—BOTH PLUNGERS WORKING TOGETHER

In any case, the attraction that draws the plunger within the coil is the product of the average intensity of magnetization within the structure of the plunger and the average magnetizing force within the solenoid. This is found true by actual test and can be proved on the principle of work by assuming the pull to be constant throughout the range or distance of travel of the plunger. In Fig. 8, either plunger, when acting separately, can do $p\,l$ units of work, wherein $p$ is the pull. The same holds true for the conditions in Figs. 9 and 10. When both plungers act together, the work done is $2\,p\,l_1$, as illustrated in Figs. 8 and 11, but the work done in both cases is the same. In Fig. 11, the two plungers can

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lift the weight $W$ equal to $2p$, but only through a distance $l_1$, which is equal to $\frac{l}{2}$. Hence the attraction or pull between a solenoid and plunger is

$$P_s = I H. \tag{4}$$

The magnetizing force at the center of a solenoid whose length is great as compared with its average radius is

$$H = \frac{0.4\ \pi\ i\ n}{L} \tag{5}$$

wherein $i$ is the current in amperes; $n$ is the number of turns in the solenoid, and $L$ is the length of the solenoid in cm.

The magnetizing force at any point on the horizontal axis of any uniformly wound solenoid is

$$H = \frac{0.2\ \pi\ i\ n\ h}{L} \tag{6}$$

wherein $h$ is the coefficient of magnetizing force which is proportional to the length and average radius of the solenoid.

Let $$\frac{\phi_i}{S} = 4\ \pi\ I, \tag{7}$$

wherein $\phi_i$ is the structual flux in the plunger and $S$ is the cross sectional area of the plunger in sq. cm.

Then $$I = \frac{\phi_i}{4\ \pi S} \tag{8}$$

Substituting (6) and (8) in (4),

$$P_s = \frac{\phi_i\ i\ n\ h}{20\ S\ L} \tag{9}$$

The pull in dynes is

$$P_d = \frac{P_s}{S} \tag{10}$$

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Substituting (**10**) in (**9**),

$$P_d = \frac{\phi_i \, i \, n \, h}{20 \, L} \tag{11}$$

The attraction in kg. is

$$P = \frac{\phi_i \, i \, n \, h}{20 \times 981{,}000 \, L} = \frac{\phi_i \, i \, n \, h}{19{,}620{,}000 \, L} \tag{12}$$

The approximate values of the coefficient of magnetizing force $h$ are found in the manner described below. The solenoid is assumed to be in the form of a hollow cylinder and to consist of a series of helices of conducting material wound at right angles to the horizontal axis. The method is based on the well known equation for the magnetizing force $H$ due to a single turn of the conductor in which current is flowing, as measured along the horizontal axis of the turn.

The expression is

$$H = \frac{0.2 \, \pi \, i \, r^2}{(r^2 + x^2)^{\frac{3}{2}}} \tag{13}$$

wherein $r$ is the average radius of the conductor as measured from the horizontal axis to the center of the cross section of the conductor, and $x$ is any point on the horizontal axis in either direction, as measured from the vertical axis; $r$ and $x$ are measured in cm.

S. P. Thompson* has shown a graphical method for determining the values of $H$ along the horizontal axis of a solenoid, which consists of plotting the $H$ curve for each turn and then adding the ordinates of all of the curves together. The first curve is due to a single turn, while the adjacent curve represents the magnetizing force due to a second turn, one centimeter from the first, plus that due to the first turn. This general idea is carried out throughout the rest of the figure. Both sides of each curve are exactly similar. Taking the maximum value of $H$ for a single turn as unity, the maximum value of $H$ at the middle of a solenoid consisting of an infinite number of turns would be two.

For the purpose of this paper, the values of $h$ have been cal-

*The Electromagnet, p. 248.

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culated for certain points, and curves drawn through these points from which any value of $H$ may be found. The method consists of dividing the length $L$ of a solenoid by its average radius $r$ and designating the quotient, or the number of sections, by $m$; each section being considered in the same manner as each single turn in the method described above.

Then

$$m = \frac{L}{r} \tag{14}$$

The magnetizing force at the center of any one section without any other section near it is

$$H_c = \frac{0.2\,\pi\,i\,n_s}{r} \tag{15}$$

wherein $n_s$ is the number of turns in one section.

At any distance $x$, as measured in section-lengths on the horizontal axis from the center of the section,

$$H_c = 0.2\,\pi\,i\,n_s\,\frac{r^2}{(r^2 + x^2)^{\frac{3}{2}}} \tag{16}$$

Let

$$q = \frac{r^2}{(r^2 + x^2)^{\frac{3}{2}}} = \frac{H_c}{0.2\,\pi\,i\,n_s} \tag{17}$$

and

$$h_a = q\,r \tag{18}$$

Then at any distance $x$ on the horizontal axis, from the center of the section,

$$h_a = \frac{r^3}{(r^2 + x^2)^{\frac{3}{2}}} \tag{19}$$

while at the center of the section, $h_a = 1$

But

$$x = r\,m_s \tag{20}$$

wherein $m_s$ is the distance in section-lengths from the center of the section.

Therefore

$$h_a = (1 + m_s^2)^{-\frac{3}{2}} \tag{21}$$

Let $a$ represent the section of reference, $m_r$ the number of sections to the right of $a$, and $m_l$ the number of sections to the left of $a$. (See Fig. 12).

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Then

$$h = \sum_{1}^{m_r} h_a + \sum_{1}^{m_l} h_a + 1 \tag{22}$$

That is, $h$ represents the sum of all of the values of $\frac{H_c r}{0.2 \pi i n_s}$ at the center of the section of reference.

The equation for $h$ at the center of either end-section may also be expressed

$$h = \sum_{1}^{m-1} h_a + 1 \tag{23}$$

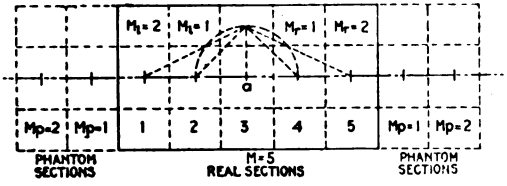


FIG. 12

For points outside of the solenoid, on the horizontal axis, at the center of any " phantom " section,

$$h = \sum_{mp}^{m+mp-1} h_a \tag{24}$$

wherein $m_p$ is the number of the phantom section.

Likewise the value of $h$ at points midway between the centers of the sections may be found by an equation

$$h = \sum_{.5}^{m_r-.5} h_a + \sum_{.5}^{ml-.5} h_a \tag{25}$$

wherein $m_r$ and $m_l$ are the number of whole sections to the right or left, respectively, from the chosen points of reference.

The equation for the phantom sections, or those points outside of the solenoid, is

$$h = \sum_{mp-.5}^{m+mp-.5} h_a \tag{26}$$

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Substituting (**17**) and (**18**),

$$h_a = \frac{H_c r}{0.2 \pi i n} \tag{27}$$

By definition

$$h = \Sigma h_a \tag{28}$$

Therefore

$$h = \frac{H r}{0.2 \pi i n_s} \tag{29}$$

whence

$$H = \frac{0.2 \pi i n_s h}{r} \tag{30}$$

The number of turns of conductor in one section is

$$n_s = \frac{n}{m} \tag{31}$$

wherein $n$ is the total number of turns in the solenoid and $m$ is the number of sections.

Substituting (**14**) and (**31**) in (**30**),

$$H = \frac{0.2 \pi i n h}{L} \tag{6}$$

When $h$ reaches its maximum value of 2, as in a solenoid whose length is great as compared with its average radius, the magnetizing force at the center is

$$H = \frac{0.4 \pi i n}{L} \tag{5}$$

In Table I, the column marked $m_s$ represents the number of sections from the section of reference $a$ as measured in either direction. The section of reference is not counted. The column $h_a$ indicates the values corresponding to $m_s$ as calculated by equation (**21**) while in the column marked $\sum_1^{m_s} h_a$ are given the sums of $h_a$ corresponding to the values of $m_s$. The value of $h_a$ for the section of reference is one. It is seen that the series of $h_a$ converges rapidly.

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TABLE I. Values of $h$.

| $m_s$ | $h_a$ | $\sum_1^{m_s} h_a$ | $\sum_2^{m_s} h_a$ | $\sum_3^{m_s} h_a$ | $\sum_4^{m_s} h_a$ | $\sum_5^{m_s} h_a$ | $\sum_6^{m_s} h_a$ | $\sum_7^{m_s} h_a$ | $\sum_8^{m_s} h_a$ | $\sum_9^{m_s} h_a$ | $\sum_{10}^{m_s} h_a$ | $\sum_{11}^{m_s} h_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .353560 | .353560 | | | | | | | | | | |
| 2 | .089443 | .443003 | .089443 | | | | | | | | | |
| 3 | .031623 | .474626 | .121066 | .031623 | | | | | | | | |
| 4 | .014267 | .488893 | .135333 | .045890 | .014267 | | | | | | | |
| 5 | .007543 | .496436 | .142876 | .053433 | .021810 | .007543 | | | | | | |
| 6 | .004443 | .500879 | .147319 | .057876 | .026253 | .011986 | .004443 | | | | | |
| 7 | .002828 | .503707 | .150147 | .060704 | .029081 | .014814 | .007271 | .002828 | | | | |
| 8 | .001908 | .505615 | .152055 | .062612 | .030989 | .016722 | .009179 | .004736 | .001908 | | | |
| 9 | .001347 | .506962 | .153402 | .063959 | .032336 | .018069 | .010526 | .006083 | .003255 | .001347 | | |
| 10 | .000985 | .507947 | .154387 | .064944 | .033321 | .019054 | .011511 | .007068 | .004240 | .002332 | .000985 | |
| 11 | .000742 | .508689 | .155129 | .065686 | .034063 | .019796 | .012253 | .007810 | .004982 | .003074 | .001727 | .000742 |
| 12 | .000573 | .509262 | .155702 | .066259 | .034636 | .020369 | .012826 | .008383 | .005555 | .003647 | .002300 | .001315 |

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In Table II, which shows the values of $h$, $m$ is the total number of sections in the solenoid and $a$ is the number of the section of reference as counted from either end of the solenoid; 1 is an end-section; 2, 3, 4, 5 and 6 are middle sections when $m$ is 3, 5, 7, 9 and 11 respectively.

TABLE II. Values of $h$.

| Sec. of Ref $a$ / $m$ | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 1.000000 | | | | | |
| 2 | 1.353560 | | | | | |
| 3 | 1.443003 | 1.707120 | | | | |
| 4 | 1.474626 | 1.796563 | | | | |
| 5 | 1.488893 | 1.828186 | 1.886006 | | | |
| 6 | 1.496436 | 1.842453 | 1.917629 | | | |
| 7 | 1.500879 | 1.849996 | 1.931896 | 1.949252 | | |
| 8 | 1.503707 | 1.854439 | 1.939439 | 1.963519 | | |
| 9 | 1.505615 | 1.857267 | 1.943882 | 1.971062 | 1.977786 | |
| 10 | 1.506962 | 1.859175 | 1.946710 | 1.975505 | 1.985329 | |
| 11 | 1.507947 | 1.860522 | 1.948618 | 1.978333 | 1.989772 | 1.992872 |

With 11 sections, the limit two at the center of the solenoid is approximated. If any solenoid be bent into the form of a ring, $h$ will have a value of two at any point along what was formerly its horizontal axis.

Table III is similar to Table I but shows the values of $h$ for points midway between the centers of the sections. Fig. 13 shows the method of finding the values of $h$ at other points between the centers of the sections. In this figure, $m = 3$.

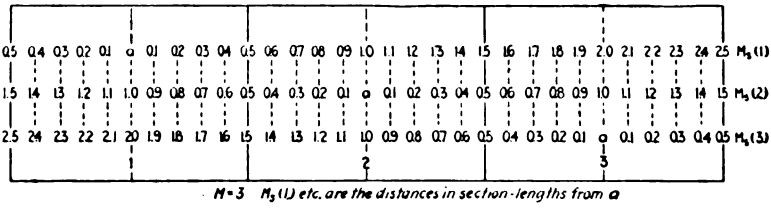


FIG. 13

The curves marked $h$ in Fig. 14 to 24 inclusive have been prepared from the above equations and tables. The peaks of the $h$ curves in Figs. 16 and 17 are slightly irregular owing to the use of points calculated for the half-sections. In Figs. 18 to 24 inclusive, only points forwhole sections were used for the peaks.

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TABLE III.

Values of $h$.

| $m_{s-.5}$ | $h_a$ | $\sum_{.5}^{m_{s-.5}} h_a$ | $\sum_{1.5}^{m_{s-.5}} h_a$ | $\sum_{2.5}^{m_{s-.5}} h_a$ | $\sum_{3.5}^{m_{s-.5}} h_a$ | $\sum_{4.5}^{m_{s-.5}} h_a$ | $\sum_{5.5}^{m_{s-.5}} h_a$ | $\sum_{6.5}^{m_{s-.5}} h_a$ | $\sum_{7.5}^{m_{s-.5}} h_a$ | $\sum_{8.5}^{m_{s-.5}} h_a$ | $\sum_{9.5}^{m_{s-.5}} h_a$ | $\sum_{10.5}^{m_{s-.5}} h_a$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.5 | .715542 | .715542 | | | | | | | | | | |
| 1.5 | .170677 | .886219 | .170677 | | | | | | | | | |
| 2.5 | .051226 | .937445 | .221903 | .051226 | | | | | | | | |
| 3.5 | .020734 | .958179 | .242637 | .071960 | .020734 | | | | | | | |
| 4.5 | .010209 | .968388 | .252846 | .082169 | .030943 | .010209 | | | | | | |
| 5.5 | .005724 | .974112 | .258570 | .087893 | .036667 | .015933 | .005724 | | | | | |
| 6.5 | .003516 | .977628 | .262086 | .091409 | .040183 | .019449 | .009240 | .003516 | | | | |
| 7.5 | .002309 | .979937 | .264395 | .093718 | .042492 | .021758 | .011549 | .005825 | .002309 | | | |
| 8.5 | .001595 | .981532 | .265990 | .095313 | .044087 | .023353 | .013144 | .007420 | .003904 | .001595 | | |
| 9.5 | .001147 | .982679 | .267137 | .096460 | .045234 | .024500 | .014291 | .008567 | .005051 | .002742 | .001147 | |
| 10.5 | .000852 | .983531 | .267989 | .097312 | .046086 | .025352 | .015143 | .009419 | .005903 | .003594 | .001999 | .000852 |
| 11.5 | .000650 | .984181 | .268639 | .097962 | .046736 | .026002 | .015793 | .010069 | .006550 | .004244 | .002649 | .001502 |

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TABLE IV

| $m_s$ | $h_a$ | $m_s$ | $h_a$ |
|---|---|---|---|
| 0. | 1.000000 | 1.1 | .304377 |
| 0.1 | .985185 | 1.2 | .262372 |
| 0.2 | .942866 | 1.3 | .226658 |
| 0.3 | .878740 | 1.4 | .196364 |
| 0.4 | .800411 | 1.5 | .170677 |
| 0.5 | .715542 | 1.6 | .148876 |
| 0.6 | .630509 | 1.7 | .130339 |
| 0.7 | .549820 | 1.8 | .113733 |
| 0.8 | .476140 | 1.9 | .101029 |
| 0.9 | .410660 | 2.0 | .089443 |
| 1.0 | .353560 | | |

The coefficient of m.m.f. for the plunger circuit is $f_p$. Its value is

$$f_p = \int_x^{l_p} h \, d \, l_p \tag{32}$$

wherein $l_p$ is any distance along the horizontal axis of the solenoid (abscissas in the figures). In this paper it represents the point at which the inserted end of the plunger rests.

The $l_p$ curves were obtained directly from the $h$ curves by integrating with a planimeter from the extreme left-hand point of each curve.

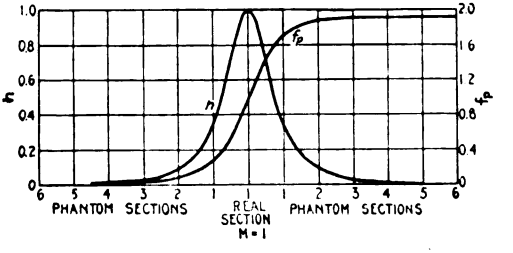


FIG. 14

In each of the above figures, the maximum value of $f_p$ approaches the limit

$$f_{max} = 2\,m \tag{33}$$

wherein $m$ is the number of sections in the solenoid. The total m.m.f. is, of course, equally divided on each side of the center of the solenoid.

A convenient method of analyzing the action of a solenoid and plunger is to think of the plunger as having been inserted

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(from the left in the figures) for a given distance, say to the middle of the solenoid, and then conceiving the m.m.f. as consisting of two components, one of which produces the magnetizing force to magnetize the plunger while the other component produces the

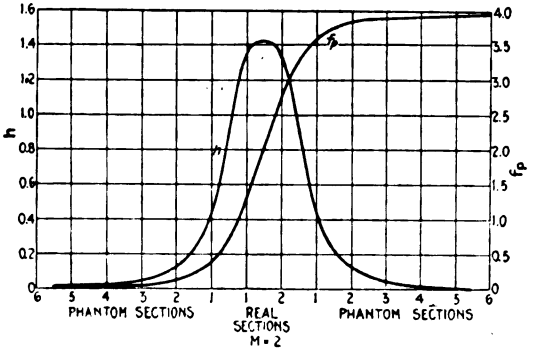


FIG. 15

magnetizing force to coact with the flux in the plunger and thus cause attraction.

The value $f_p$ bears the same relation to the m.m.f., $F_p$, that $h$ bears to the magnetizing force. Therefore,

$$F_p = 0.2\,\pi\,i\,n\,f_p \qquad (34)$$

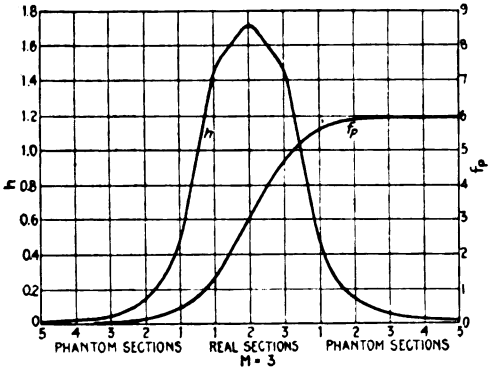


FIG. 16

Hence, at the middle of any solenoid, the m.m.f. available to magnetize the plunger is but one-half of the total while, at other points along the horizontal axis of the solenoid, the values of $f_p$ are to be read from the curves.

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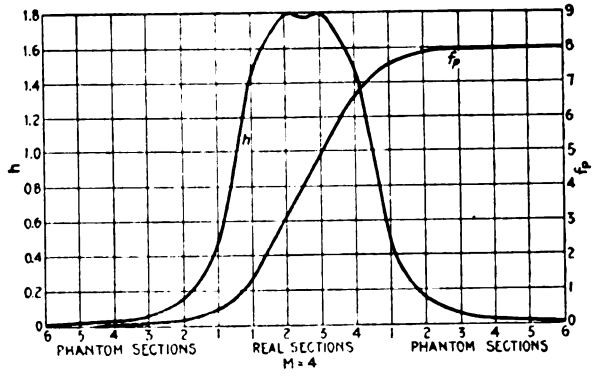
The magnetic circuit of the plunger may be considered as consisting of that portion of the plunger which is inserted into the solenoid and the surrounding air or non-magnetic region between the inserted end of the plunger and the end of the solenoid at




FIR. 17

which the plunger enters. Actually, the flux enters or leaves the protruding plunger over the entire area of that part of the plunger. Practically, it is convenient to assume that it enters the plunger between a point, equal to one-half of one section-length from the

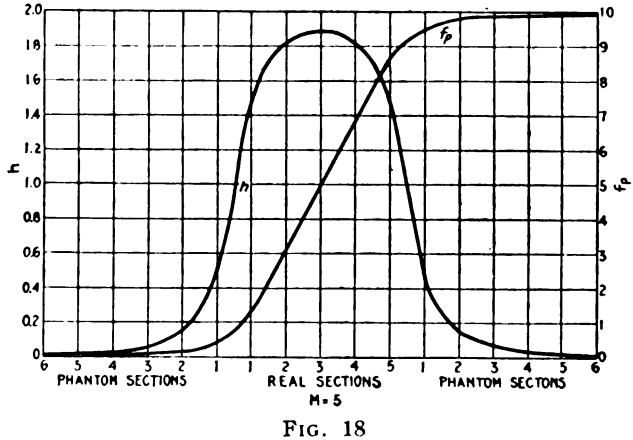



FIG. 18

end of the solenoid at which the plunger enters, and the middle of the plunger. This makes it possible to consider the point $l_p$ as being at the center of the section of the same number as the point. Thus, at the center of the third section from, say, the left-hand end of the solenoid, $l_p = 3$.

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As the plunger passes into the solenoid, the iron flux $\phi_i$, which is equal to $S(B - H)$, increases and the pull, for a constant value of $H$, will increase directly with $\phi_i$ until saturation is attained. Thereafter, the pull

$$P = \frac{\phi_i \, i \, n \, h}{1962 \, L} \times 10^{-4} \tag{12}$$

will remain constant.

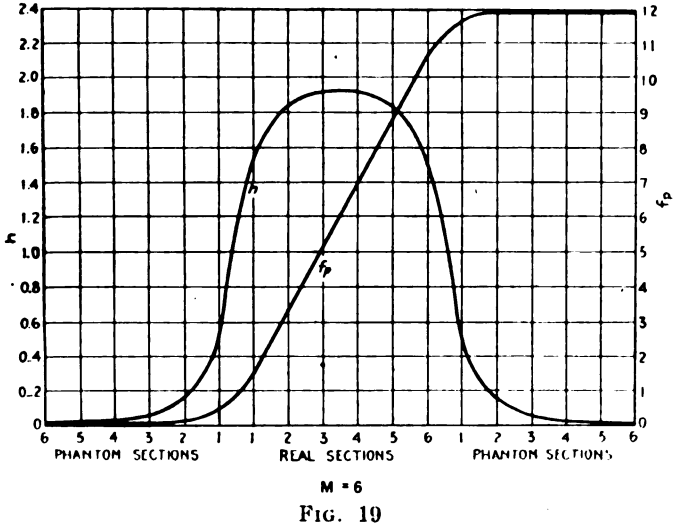


FIG. 19

After the plunger is saturated, the pull will vary directly with $H = i \, n \, h$. That is, the pull will be

$$P = \frac{H \, S \, (B - H)}{1962 \, L} \times 10^{-4} \tag{35}$$

The plunger or iron flux $\phi_i$ may be called the average effective flux.

One portion of the plunger m.m.f. is required to overcome the reluctance of the plunger, and the other portion forces the flux through the air from the inserted end of the plunger to the end of the solenoid at which the plunger enters.

This leads to the problem of ascertaining the reluctance of the air-return circuit. The mean length of this portion of the plunger circuit is somewhere between 0 and $\infty$ while the cross section is

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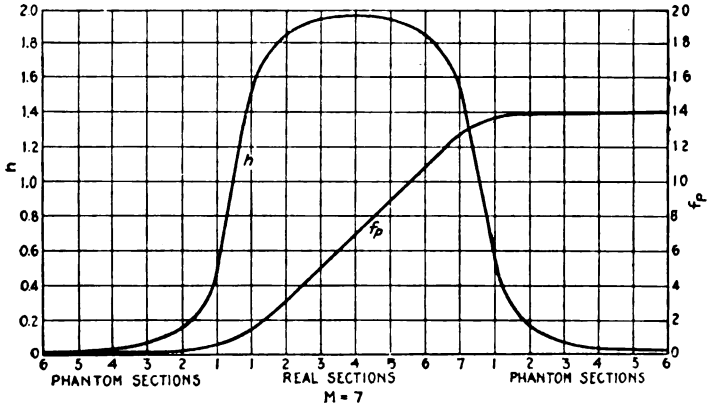


FIG 20

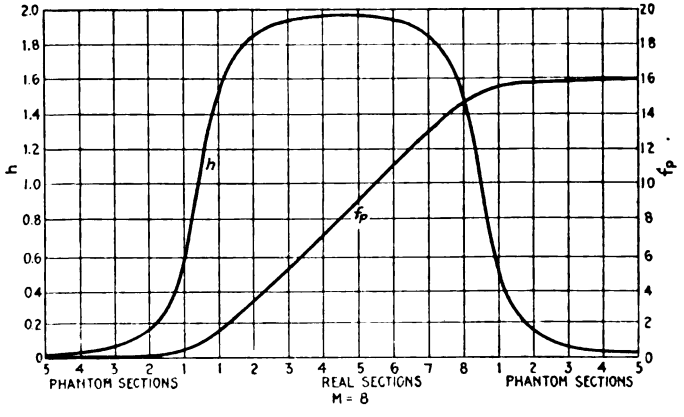


FIG. 21

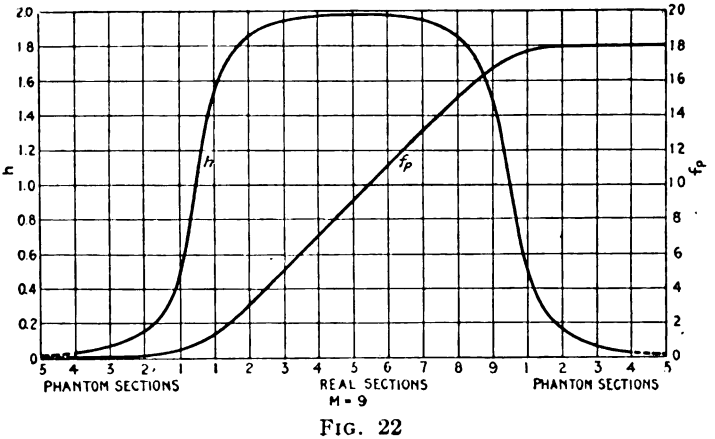


FIG. 22

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infinite. It is difficult to obtain accurate experimental data owing to the fact that the plunger is not uniformly magnetized but may be saturated at or near the middle of that portion within the solenoid with lessening degrees of magnetization on either side of this point.

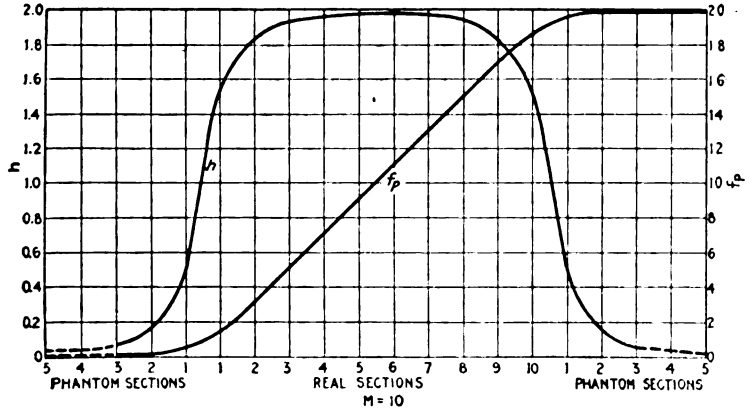


FIG. 23

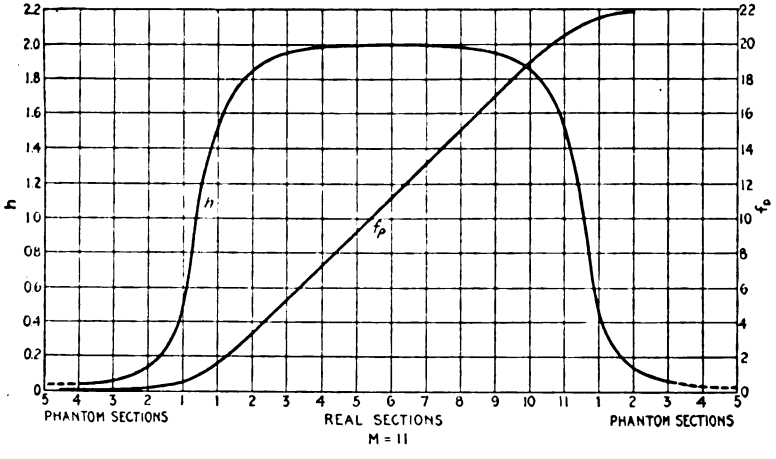


FIG. 24

The average reluctance of the air portion of the plunger circuit is the difference between the total average reluctance of the plunger circuit and the reluctance of the plunger.

$$R_a = \frac{F_\rho}{\phi_i} - \frac{l_\rho r}{S(\mu_i - 1)} \qquad (36)$$

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wherein $\phi_i$ is the total flux in the plunger circuit, $l_p$ is the length of the plunger, in section-lengths, inserted into the solenoid, $S$ the cross-sectional area of the plunger is sq. cms., and $\mu_i$ the average permeability of the plunger.

In Fig. 25 are shown the test characteristics of an eleven-section solenoid 30.5 cm. long and of 2.76 cm. average radius. The plunger was of Swedish iron 6.45 sq. cm. in cross section and one meter is length. The two dotted curves represent the values of $h$ plotted to such scales as to be readily compared with the corresponding pulls.

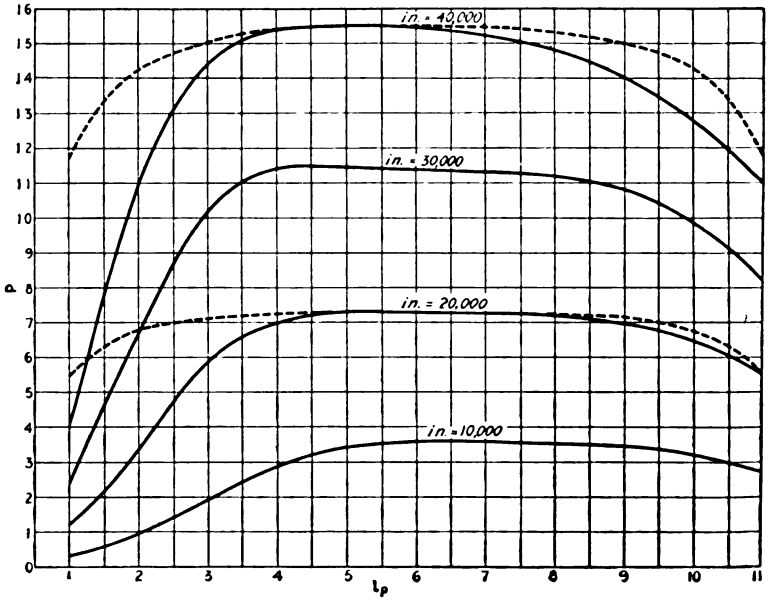


FIG. 25

The average plunger flux is calculated from these data by rearranging (12). Then

$$\phi_i = 1962 \frac{P L}{i n h} \times 10^{-4} \qquad (37)$$

Fig. 26 shows the calculated values of $\frac{\phi_i}{S}$ plotted against points representing the centers of the sections of the solenoid. The calculated values of $\frac{F_p}{\phi_i}$ are also plotted in Fig. 26. The average

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air reluctance can only be calculated from the test data below saturation. The slopes of the curves indicate that the total reluctance below saturation is less than 0.1 oersted.

The calculated flux-densities are necessarily, only averages. Owing to the relatively low calculated reluctances with the lower m.m.fs., it is evident that the inserted plunger may be highly saturated at and near the middle of that part inserted. As the m.m.f. is increased, a greater portion of the inserted plunger be-

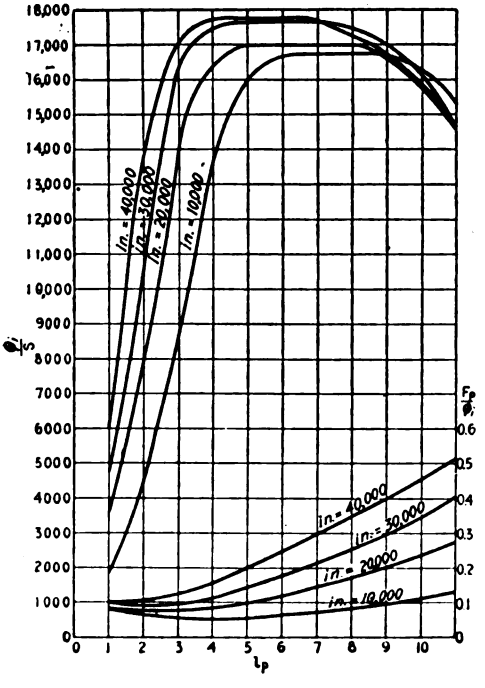


FIG. 26

comes highly saturated; but the entire inserted portion will not be uniformly magnetized, owing to the leakage from all parts of its surface.

Under these conditions, the average reluctance of the plunger might be in excess of that of the air-portion of the magnetic circuit. In the case of the eleven-circuit solenoid, the length of the coil was 30.5 cm. The cross-sectional area of the plunger was 6.45 sq. cm. The reluctance of that portion of the plunger inserted into the entire length of the solenoid would, therefore,

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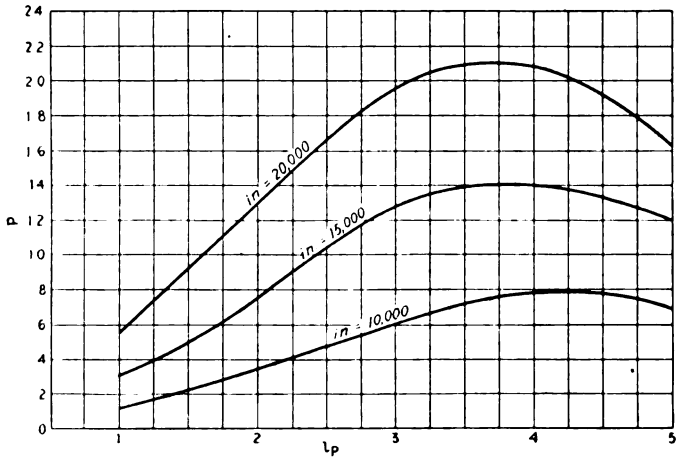


FIG. 27

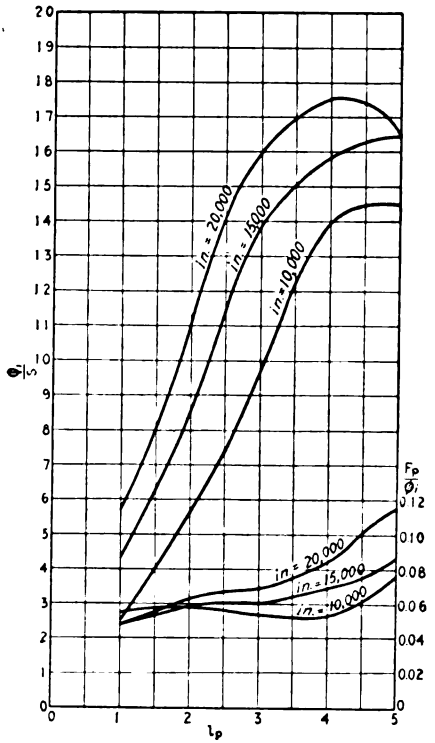


FIG. 28

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be 4.73 oersteds with unit permeability. With an average permeability of 20, the average reluctance would be 0.237 oersted, exclusive of that of the air-return circuit.

Fig. 27 shows the results of a test of a five-section solenoid of 3.5 cm. average radius. The plunger was of cold-rolled steel 11.4 sq. cm. in cross section and approximately 25 cm. long. The length of the solenoid was 17.8 cm. Fig. 28 shows the calculated flux-densities and reluctances. This figure shows lower total reluctances owing to the greater cross-section of the plunger.

The reluctance of the nonmagnetic region surrounding a plunger must be nearly constant throughout the entire travel of the plunger because the leakage area of the plunger increases directly with the distance that the plunger is inserted into the solenoid. This

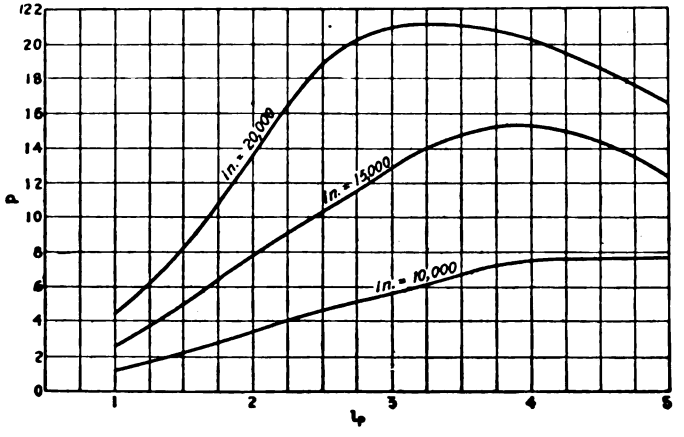


FIG. 29

leakage surface is directly proportional to the diameter of the plunger. The diameters of the plungers used in the tests of the eleven-section and five-section solenoids were 2.8 cm. and 3.8 cm. respectively. Hence, the ratio of the reluctance of the surrounding air-spaces should be as 1 to 0.74. Taking the air reluctance of the five-section solenoid as 0.06 oersted, that for the eleven section solenoid should be 0.081 oersted. The air reluctances are probably lower than assumed.

In Fig. 29 are shown the calculated characteristics of the five-section solenoid, the assumptions being that the total reluctance of the plunger circuit has a constant value of 0.06 oersted and that the limit of the average structural flux density is 17,000. The calculated flux densities are shown in Fig. 30.

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Fig. 29 compares favorably with Fig. 27, excepting that the maximum pull due to 15,000 ampere-turns is in excess of the test data, and the maximum pull due to 20,000 ampere-turns occurs at a point somewhat to the left of the point observed in the test. This is largely due to the straight-line magnetization curve assumed as in Fig. 30. It is to be observed that the pulls at other points on the curves compare favorably with the test data, proving that the reluctance of the air-portion of the magnetic circuit must be low.

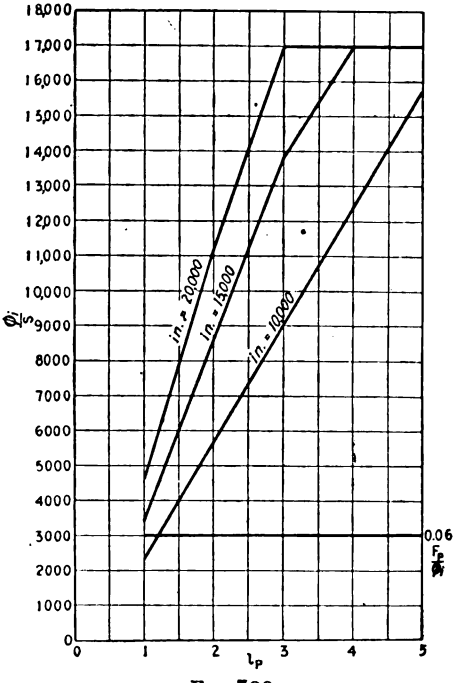


FIG. 30

Fig. 31 shows the calculated characteristics of the eleven-section solenoid. The assumptions are the same as those used in the calculation of the five-section solenoid, excepting that the assumed constant reluctance is 0.081 oersted. The calculated flux-densities are shown in Fig. 32.

The remarks regarding Fig. 29 apply to Fig. 31 also. The pulls do not become at a maximum at the same points as in the test curves and there is some variation in these pulls. The former is to be expected with a straight-line magnetization curve from

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zero to saturation. The reluctances of the plungers vary with different degrees of magnetization and the saturation points of the plungers, as well as constant reluctances, are assumed. The test data indicate that the total reluctance varies with the m.m.f.

The effects of the apparent reaction which takes place as the magnetic center of the plunger approaches the magnetic center of the solenoid, are evident in Fig. 28. As is well known, all relative movement ceases when these two points coincide. In these tests, the plungers were considerably longer than the solenoids.

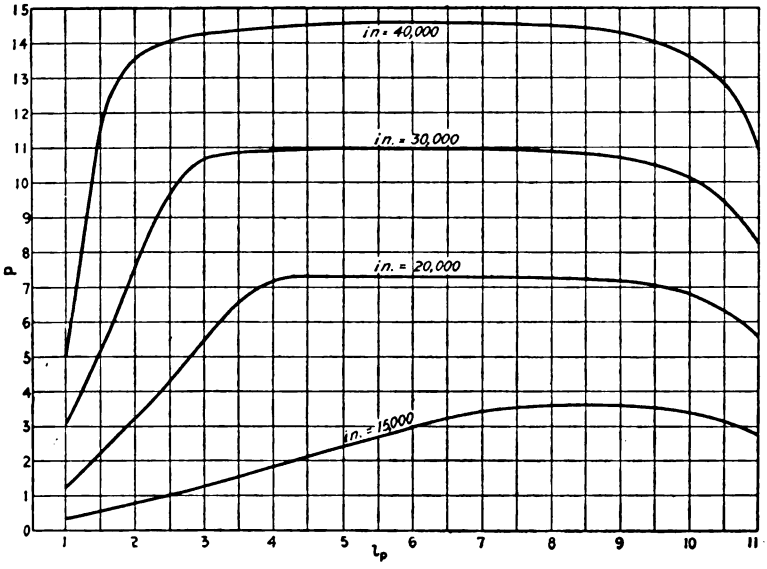


FIG. 31

Figs. 27 and 29 illustrate the action of a solenoid-and-plunger very nicely. When the flux density in the plunger is low, the maximum pull may occur at a point near the end of the solenoid opposite to that at which the plunger enters, whereas, with high flux-densities, the maximum pull may occur when the inserted end of the plunger is at the middle of the solenoid. The pull cannot be at a maximum at points between the middle of the solenoid and the end at which the plunger enters, although it may be nearly uniform for equal distances on both sides of the middle, in cases of long solenoids. In cases of very short solenoids

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the maximum pull may occur at points outside of the solenoid at the end opposite to that at which the plunger enters.

Owing to the low reluctances of the plunger circuits of this type of electromagnet, the equation

$$P_d = \frac{\phi_i^2}{8\pi S} \tag{38}$$

cannot be applied to predetermine the pull due to plunger electromagnets, excepting for zero air gap. Equation (**38**) is not general

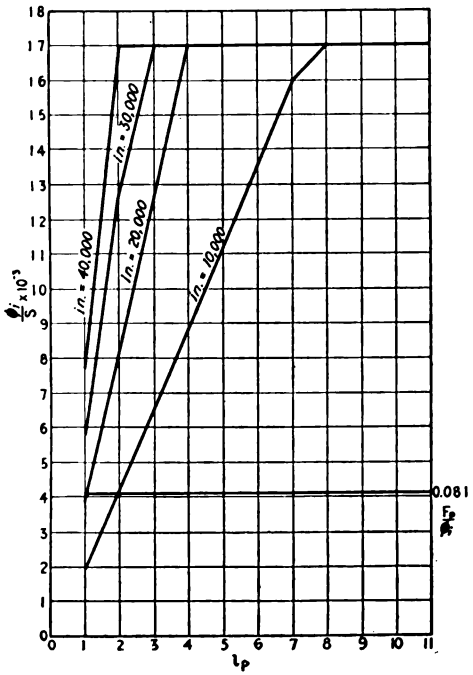


FIG. 32

but is for the attraction proportional to $(B - H)^2$ between the plunger and the stop only. On account of the leakage from the end of the inserted plunger back through the air and frame to the end of the solenoid at which the plunger enters, when there is an air gap, the flux densities in the plunger may be much greater than assumed, when the assumption is that nearly all of the flux passes through the air gap.

The magnetic circuit of an iron-clad stopped solenoid, or plunger electromagnet, consists of more than one path. The m.m.f.

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forces flux through the air gap but it also forces another flux from the end of the plunger through the air and frame and back to the opposite end of the plunger. This latter flux produces a relatively strong pull whether any flux passes through the air gap, between the plunger and the stop, or not. There are, therefore, two separate and distinct actions to be considered, viz: the pull due to the flux density, $B - H$, in the air gap and the pull due to the flux in the plunger coacting with the magnetizing force due to the ampere turns in the solenoid.

One of the assumptions upon which Maxwell's fundamental equation is based, is that there is no air gap whatsoever between the abutting ends of the hypothetically-separated core of the bar electromagnet. Hence Maxwell's equation was not intended for tractive electromagnets. The conditions imposed by Maxwell clearly indicate that no work can be done by such an electromagnet. It is further assumed that the magnetic circuit is identical with that of a bar electromagnet; that is, that the flux is equally distributed on each side of the middle of the hypothetical zero air gap and that there is no leakage whatsoever from the abutting ends of the half-cores back to the opposite end of the same half-core.

Therefore, the conditions imposed for the application of Maxwell's fundamental equation (**38**) are entirely different from those met with in tractive electromagnets; particularly that type known as the plunger electromagnet.

In the application of equation (**38**) it is customary to add together the reluctances of the air gap, plunger, stop, frame and the non-magnetic joint between the plunger and the frame where the former passes through the latter. The total m.m.f. is then divided by the total reluctance and the resulting flux is assumed to be the total flux in the magnetic circuit, and to be the same in the air gap as in the plunger and stop. Allowance for leakage is seldom made because the pulls, with moderately long air gaps, are usually found to be in excess of those calculated. The total flux divided by the cross sectional area of the plunger is called the magnetic induction $B$ in the plunger and this value is also usually assumed for the flux-density in the air gap. When the reluctance of the air gap is equal to the sum of the reluctances of the rest of this single magnetic circuit, the maximum amount of work is assumed to be obtainable, when work is defined as initial pull $\times$ length of air gap.

The total pull, by Maxwell's equation (**3**), as modified by

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neglecting the last term of the right hand member (which is not available in a solid coil), is

$$P_s = 2\pi I^2 + I H \tag{39}$$

in dynes per sq. cm.

$$P_i = 2\pi I^2 \tag{40}$$

is the structural pull, in dynes per sq. cm., between the abutting ends only of the half-cores of the bar electromagnet.

Now when an air gap is introduced between the plunger and the stop, the intensity of magnetization in the iron does not decrease with the flux density (less $H$) in the air gap on account of the leakage from the inner end of the plunger, through the air or ether, back to the end at which the plunger enters the coil.

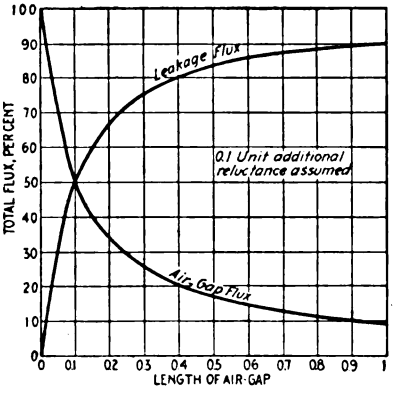


FIG. 33—RELATIVE VALUES OF FLUX

This leakage tends to sustain the intensity of magnetization in the plunger and to produce the "solenoid pull" when the flux density (less $H$) in the air gap is exceedingly low, or when there is no air gap (in the usual sense) as when only the plunger is inserted into the coil and there is no other magnetic material near.

Generally speaking*, the leakage pull is a maximum when the length of the air gap in a plunger electromagnet is maximum, but when the length of the air gap is reduced to zero, there can be no leakage (as mentioned above) whatsoever, and the law of the pull required to separate the plunger from the stop is then expressed by equation (39). On the other hand, the air gap

*See "Alternating-Current Electromagnets," *Electrical World*, Vol. 63, No. 5, p. 260 (1914).

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flux will vary inversely with the length of the air gap so that the general conditions, so far as the air gap and leakage fluxes are concerned, are graphically represented in Fig. 33.

It will now be seen that Maxwell's law is true for a closed air gap, under the ideal conditions previously mentioned, but that it does not hold for tractive electromagnets unless modified to allow for the extra pull due to leakage. Therefore, the equation for the total pull due to a plunger electromagnet with an air gap and fixed stop may be constructed as follows: From (**7**), $\frac{\phi_i}{S} = 4\pi I$, wherein $\phi_i$ is the total structural flux in the iron. Let $\phi_g$ represent the flux in the air gap less that due to the magnetizing force, and allow $P_g$ to represent the pull in dynes per sq. cm. in the air gap due to $\phi_g$. Then

$$P_g = \frac{\phi_g^2}{8\pi S^2} \tag{41}$$

Expressed in dynes,

$$P_g = \frac{\phi_g^2}{8\pi S} \tag{42}$$

The pull in kilograms, under the above conditions, is

$$P_G = \frac{\phi_g^2}{8\pi \times 981{,}000\, S} = \frac{\phi_g^2}{247\, S} \times 10^{-4} \tag{43}$$

Adding equations (**43**) and (**12**), the total pull, in kilograms, for a plunger electromagnet, with or without an iron frame, or a stop, is

$$P = \left(\frac{\phi_g^2}{247\, S} + \frac{\phi_i\, i\, n\, h}{1962\, L}\right) \times 10^{-4} \tag{44}$$

which is the general pull equation for tractive electromagnets of the plunger type.

The flux in the stop also coacts with the magnetizing force in the coil which tends to produce motion but the stop and coil are usually fixed in position so that no relative motion results. The leakage, from the inserted end of the stop back through the air and frame to the place where it is attached to the frame, tends to cause a greater total flux to pass through the stop than is usually calculated. This causes the reluctance of the stop to be greater than calculated on the assumption that the flux in the plunger and stop is the same as that in the air-gap.

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In Fig. 34* are shown the test characteristics of the eleven-section solenoid, 30.5 cm. long, surrounded by a massive wrought iron frame. The stop was of the same material and of the same diameter as the plunger and was inserted 7.6 cm. into the coil. All curves are due to 10,000 ampere-turns. The curve $P_t$ is due to the plunger electromagnet complete; that marked $P_s$ is due to the solenoid-and-plunger only, and the curve marked $P_g$ is the difference between the above curves. Hence

$$P_g = P_t - P_s \tag{45}$$

represents the pull due to the flux in the air-gap. $l_g$ is the length of the air gap in cms.

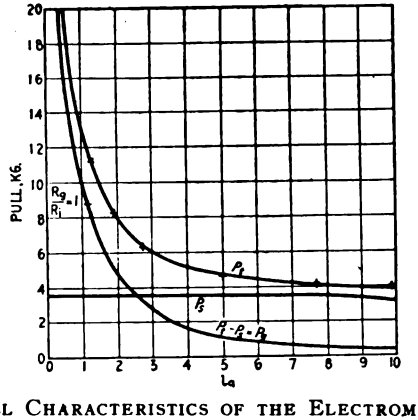


FIG. 34—PULL CHARACTERISTICS OF THE ELECTROMAGNET TESTED

The points marked on the curve $P_t$ are the actual test data for the total pull. The rest of the curve $P_t$ was calculated in the manner described below.

In what follows, the reluctance $R_g$ of the working air gap is assumed to vary directly with the distance between the plunger and the stop. A trial calculation from the test data indicated a nearly-constant reluctance, external to the working air-gap, of 0.17 oersteds. Taking this as a basis, the curve $P_t$, which agrees closely with the test data, was obtained by adding the calculated air-gap pulls to those due to the solenoid-and-plunger only.

*Part of the following is abstracted from *Electrical World*. Vol. 59, No. 25, p. 1388 (1912).

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The m.m.f. for the air gap is

$$F_g = \frac{R_g F_t}{R_g + R_i} \tag{46}$$

wherein $F_t$ is the total m.m.f. (12,570 gilberts), $R_g$ the reluctance of the working air gap and $R_i$ the sum of the reluctances of the plunger, stop, frame, and non-magnetic joint between the plunger and the frame. Then the flux in the air gap is

$$\phi_g = \frac{F_g}{R_g} \tag{47}$$

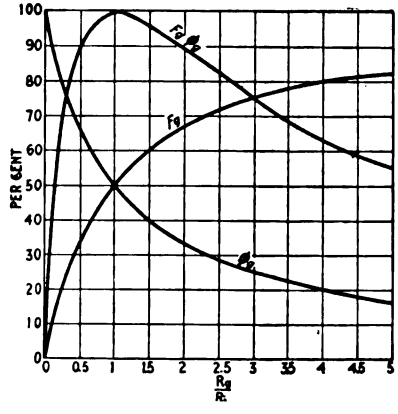


FIG. 35—FORCE, THEORETICAL FLUX AND ENERGY CURVES FOR AIR GAP

The pull due to the flux in the air gap was calculated by equation (43).

It has been theoretically proved that the maximum amount of work (initial pull × length of air gap) may be obtained from a plunger electromagnet when the reluctance of the working air-gap is equal to that of the rest of the magnetic circuit.* This is similar to the rule for the maximum wattage which may be obtained in an electrical apparatus connected in series with a line. The general principle is illustrated in Fig. 35, wherein $R_i$ is assumed to be constant. The product of m.m.f. and flux, in the air gap, becomes a maximum when $R_g = R_i$. $F_g \phi_g$ is, in a way, analogous to the e.m.f. multiplied by the current strength.

*E. R. Carichoff, *Electrical World*, Vol. XXIII, pp. 113 and 212 (1894).

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The point marked $\frac{R_g}{R_i} = 1$, on the curve $P_g$ in Fig. 34, is where the reluctance of the air gap is 0.17 oersted, which is the same as the calculated reluctance for the rest of the magnetic circuit.

Fig. 36 shows the calculated air gap characteristics of the test

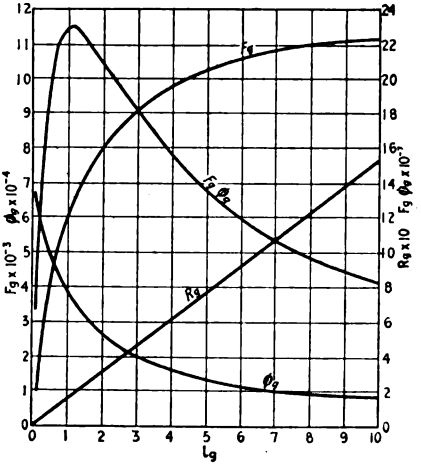


FIG. 36—CALCULATED AIR GAP CHARACTERISTICS OF TEST ELECTROMAGNET

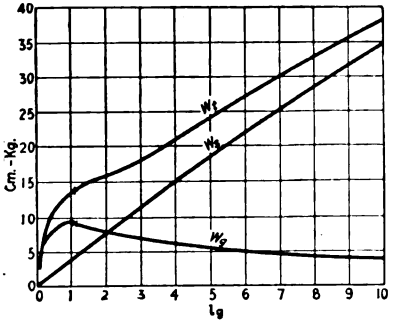


FIG. 37—WORK CURVES OF TEST ELECTROMAGNET

electromagnet. The calculated values of $F_g \phi_g$ become at a maximum when the air gap is 1.1 cm. in length, which is the point where $R_g = R_i$.

The centimeter-kilograms of work, for varying lengths of air gap, obtained with the test electromagnet, are shown in Fig. 37. $W_t$ is the pull $\times$ distance which was actually obtained with the

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complete plunger electromagnet, while $W_s$ is the actual pull $\times$ distance obtained with the coil-and-plunger only. The curve marked $W_g$ represents the difference between curves $W_t$ and $W_s$.

Therefore, the maximum amount of work as defined above which may be obtained with a plunger electromagnet, with a given m.m.f., is not directly dependent upon the equality of the reluctance of the air gap and the sum of the reluctances of the rest of the magnetic circuit.

The amount of work which may be obtained with a plunger electromagnet becomes at a maximum when the range or distance of travel of the plunger times the sum of the pulls, due to the flux in the air gap and to the flux in the plunger coacting with the magnetizing force, become at a maximum.

The latter rule is general and is applicable to all forms of plunger electromagnets, with or without stops or frames, whether designed for alternating or direct currents. When the air gap reluctance and total m.m.f. are of low value, the pull due to the "solenoid effect" may be negligible but this pull increases with the m.m.f. and is very marked when the air gap reluctance is relatively high.

The designs of alternating and direct-current plunger electromagnets differ, generally, only in their windings and ferric parts; the law governing the mean effective pull applies to both.

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*To be presented at the 294th Meeting of the American Institute of Electrical Engineers, Washington, D.C., April 24-25, 1914, under the auspices of the Electrophysics Committee.*

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(*Subject to final revision for the Transactions.*)

# A MILLIAMPERE CURRENT TRANSFORMER

BY EDWARD BENNETT

ABSTRACT OF PAPER

(1) It is pointed out that by the use of a current transformer having a primary to secondary current ratio of the order of 1 to 100, oscillograms can be obtained of the charging current of a single high-tension insulator or of a few feet of high-tension transmission line; that is, oscillograms of currents of the order of 0.1 to 0.5 milliampere may be obtained.

(2) The drawing and specification are given for a transformer for this purpose.

(3) The transformer relations are discussed; the methods of determining the transformer constants are outlined, and the performance of transformers constructed in accordance with the specifications is determined.

(4) A series of oscillograms is given to illustrate some of the applications of the transformer, such as to the study of corona, high-tension insulators, and leakage currents in evacuated lamps.

## I—INTRODUCTION. PURPOSE OF THE TRANSFORMER

IN AN investigation of the merits of wooden insulator pins and of the causes of pin charring, conducted in 1908 for the Telluride Power Company, the writer had occasion to construct a current transformer which would permit of obtaining oscillograms of the displacement current across a single high-tension insulator. Since then a similar transformer has been used to determine the effect of corona on the wave form of the displacement current between a 10-ft. (3-m.) length of wire and a concentric 14-in. (35.56-cm.) pipe.

The first transformers were designed to have a current ratio of 100, but on test developed a ratio of only 89; moreover, it was evident that high harmonics were getting through primary winding as a displacement current from layer to layer.

Computations, based on the assumption that the primary was wound in layers, had indicated that displacement current between layers at 60 cycles would be less than 0.2 per cent of total current. After the test, these computations were rechecked with the same results as before, and for some time the discrepancy remained inexplicable. The cause of the discrepancy was eventually discovered and eliminated only by a chance observation.



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In view of this experience and of the merits of the transformer for certain lines of investigation, a description of the construction and characteristics of the perfected transformer would seem to be warranted and is herewith presented.

*Purpose of the Transformer.* A deflection of one centimeter on oscillograms from the oscillograph used is obtained with a

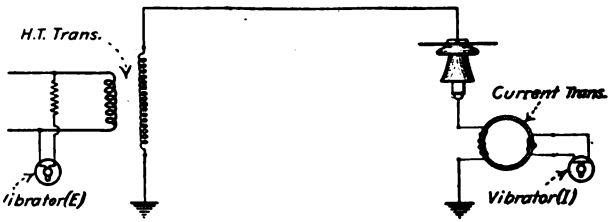


FIG. 1—CONNECTIONS FOR INSULATOR OSCILLOGRAMS

current of from 0.05 to 0.08 peak ampere. Oscillograms with a peak deflection of less than 0.5 cm. are not very satisfactory, therefore the smallest current which will give a satisfactory oscillogram when passed directly through the vibrator of the oscillograph is 0.02 effective ampere.

The displacement current at the working voltage from the line

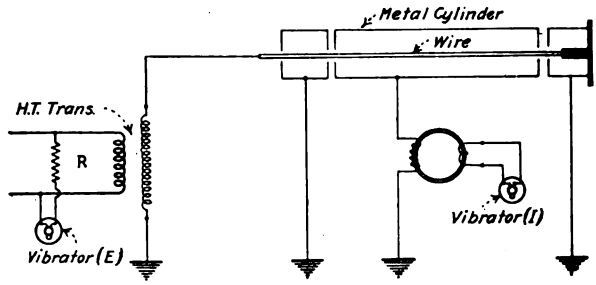


FIG. 2—CONNECTIONS FOR OSCILLOGRAM OF THE CHARGING CURRENT OF A WIRE

wire to the pin of a single high-tension insulator is about 0.0002 ampere at 60 cycles, that is, it is approximately the same as the charging current of six ft. (1.8 m.) of No. 00 B. & S. conductor at 34.6 kv. to ground. Oscillograms of these currents may be obtained by using a current transformer with a current ratio of 100 as shown in Figs. 1 and 2.

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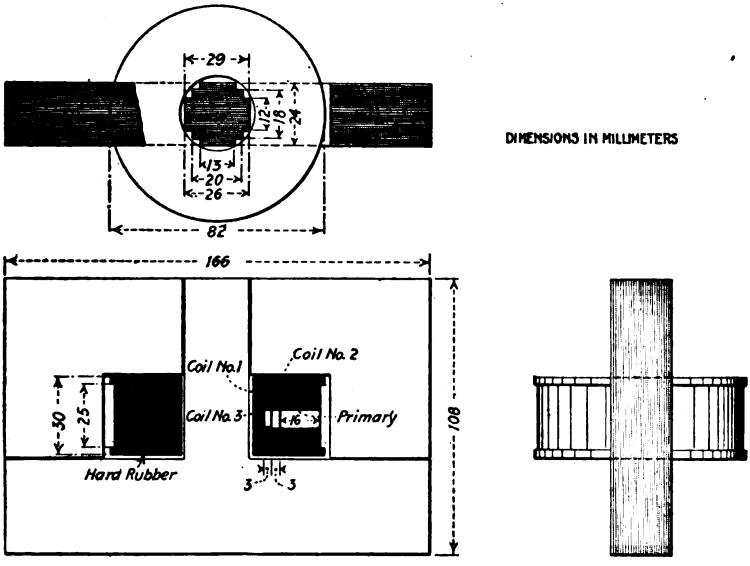
## II—Description of the Transformer

The construction and dimensions of the transformer are shown in Figs 3 and 4. Primary and secondary coils are wound on a single hard rubber spool, the secondary coils being at the bottom of the spool The magnetic circuit comprises a short bridge section within the spool and two wings of greater length but each having 1.8 times the cross section of the bridge. The laminated core is clamped between two maple blocks on which are mounted the binding posts in which the coils terminate.




Figs. 3 and 4—Millampere Current Transformer

### Specification

*Rating.*

Secondary current range 0.01 to 0.1 ampere.
Ratios of current transformation 100 and 200.
Primary current range 0.00005 to 0.001 ampere.
Frequency 60 cycles.
Resistance of external circuit 0.6 ohms.
Reactance " " " negligible

The 200 ratio is for use only in those cases in which very exact phase relations are not essential.

*Primary Winding.*

16,200 turns of 38 B. & S. gage enameled copper wire.

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Mean diameter of turn 6.3 cm.
Total length of wire 3210 meters.
Measured resistance 6650 ohms.

The wire is not wound in single layers but in " sections " of about 600 turns each with a layer of 0.04-mm. tissue paper between sections.

*Secondary Winding.*

Number of coils 3.
Size of wire No. 20 B. & S. double silk covered copper.
Coil 1 has 1 layer of 27 turns.
Resistance, 0.11 ohms.
Coil 2 has 81 turns in 3 layers.
Resistance 0.34 ohms.
Coil 3 has 81 turns in 3 layers.
Resistance 0.38 ohms.

Coils 2 and 3 are used in series for a ratio of 100 and in parallel for a ratio of 200.

*Core.*

14-mil. (0.36-mm.) silicon steel.
Net section of bridge section 4.2 sq. cm.
Magnetic length of bridge section about 5 cm.
Net section of each wing 7.7 sq. cm.
Magnetic length of wing section 15 cm.
Flux densities at 0.05 ampere secondary:
36 lines per sq. cm. in bridge.
10 " " " " " wings.
Joints in the magnetic circuit, 2.

## III—Transformer Relations

Fig. 5 is a vector diagram showing the phase relations of currents, voltages, and magnetic flux when the transformer is connected for a ratio of 100 and is delivering 0.05 ampere (effective value) to the secondary circuit. Unless otherwise stated, the following discussion all relates to the 100 to 1 connection of the transformer.

In this diagram,

if $I_2 = 0.05$ amperere presents the current in the secondary then

$E_2 = 0.05\ (r_2 + jx_2)$ represents the voltage that must be induced in the secondary by the magnetic flux.

$E_2 = I_2\ (r_2 + jx_2)$ is the resultant of the two components,

$I_2r_2$ in phase with the secondary current; and

$I_2x_2$, leading the secondary current by 90 deg., where

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$r_2$ is the resistance of the secondary winding plus the resistance of the external circuit supplied by the secondary, and

$x_2$ is the reactance of the secondary winding due to leakage flux embracing the secondary alone, plus the reactance of the external circuit.

The secondary voltage $E_2$ is induced by the mutual magnetic flux, 90 deg. in advance of and directly proportional to $E_2$.

To drive the flux $\varphi$ through the magnetic circuit there is required a magnetizing force consisting of two components, a wattless component $M$ in phase with $\varphi$, and a power component $W$, 90 deg. in advance of $\varphi$. The primary current $I_1$ must furnish this magnetizing force and must in addition neutralize the magnetomotive force of the secondary current $I_1$.

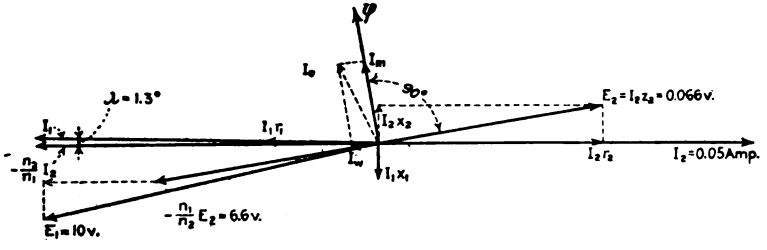


FIG. 5—TRANSFORMER DIAGRAM

The primary current then is the resultant of three components:

First, a neutralizing component $I_n = -\frac{n_2}{n_1} I_2$ or

in phase opposition to $I_2$.

Second, a wattless exciting component $I_m$ in phase with $\varphi$;

Third, a power exciting component $I_w$, 90 deg. in advance of $\varphi$.

The voltage $E_1$ consumed in the primary of the transformer is made up of three components.

First, the voltage consumed by the mutual flux

$$\varphi, = -\frac{n_1}{n_2} E_2.$$

2nd the voltage consumed by resistance in the primary, a voltage in phase with $I_1$, and equal to $I_1 r_1$;

Third, the voltage consumed by leakage flux linking with the primary alone, a voltage 90 deg. in advance of $I_1$ and equal to $jI_1 x_1$.

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It is seen from this diagram that the reversed secondary current leads the primary current by a small angle, $\lambda$, whose tangent is approximately equal to the component of the exciting current in quadrature to the load current divided by the load current. Furthermore, the ratio of the secondary to primary current is less than the ratio of primary to secondary turns, due to the component of the exciting current in phase with the load current.

## IV.—Determination of the Transformer Constants

*Resistance.* The resistance of the secondary circuit is as follows:

| | |
|---|---|
| Secondary winding | 0.62 ohms |
| Leads to the oscillograph (negligible) | |
| Vibrator of the oscillograph | 0.6 " |
| Total secondary resistance | 1.32 " |

Reduced to the primary the equivalent resistance is 13,200 ohms.

The reactance of the primary is 6600 ohms, making a total transformer and vibrator resistance of 19,850 ohms.

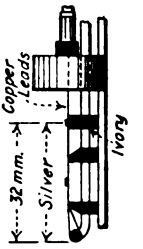


Fig. 6—Modified Vibrator

It will be noted that the resistance given for the vibrators, (0.6 ohms), is only one half of the resistance of the standard vibrators. This reduction in the resistance has been effected by modifying the vibrators as shown in Fig. 6. This modification eliminates useless silver strip, reducing the length of the strip to one half the standard length, without in any way affecting the period or sensitiveness of the vibrator. It is of course out of the question to fuse vibrators used in the secondary of the current transformer because of the high resistance of the fuse.

*Reactance.* The reactance of the external part of the secondary circuit is negligible in comparison with the reactance of the secondary winding.

The separate reactances of primary and secondary due to leakage flux cannot be computed from the transformer dimension with any degree accuracy. The combined leakage reactance of primary and secondary can, however, be obtained experimentally by taking an oscillogram with the connections shown in Fig. 7. Fig. 8 (film 203) is a characteristic oscillogram taken with these connections. The current in the secondary lags about 12 degrees

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behind the potential across the primary. With a transformer and a vibrator resistance of 19,850 ohms, a lag of 12 deg. indicates a leakage reactance of 4200 ohms at 60 cycles.

It will be approximately correct, and will introduce no appreciable error to apportion half of this to the primary and half to the secondary, thus making the primary reactance 2100 ohms and the secondary reactance 0.21 ohms. Fig. 5 has been constructed on this basis.

*Flux Densities.* With a total secondary impedance of 1.33 ohms = $(1.32 + j\,0.21)$, the secondary voltage at 0.05 ampere is 0.066 volt. To generate this voltage, the flux densities must be 36 lines per sq. cm. in the bridge and 10 lines per sq. cm. in the wings. Data are not available for the predetermination of the exciting current at these low flux densities.

*Phase Displacement and Ratio of Transformation.* To determine the phase displacement between primary and secondary

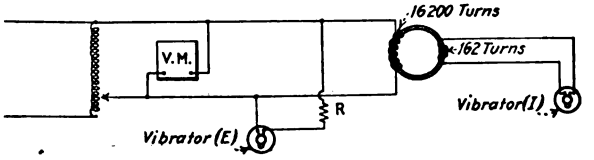


FIG. 7—CONNECTIONS FOR THE DETERMINATION OF TRANSFORMER REACTANCE

currents and the ratio of transformation, oscillograms were taken with the connections shown in Figs. 9 and 12. As shown in Fig. 9, a 60-cycle current, mesaured by a voltmeter $A$, is passed through one of the 81-turn coils and through the vibrator $P$. The second 81-turn coil is connected through an adjustable resistance $R$ to the vibrator $S$ which was calibrated before and after these tests.

For small variations in the resistance of the secondary circuit, the angle of phase displacement and the percentage reduction in the multiplier are approximately proportional to the secondary resistance. The additional resistance $R$, which was varied from zero to three ohms, was inserted for the purpose of increasing the angle of phase displacement, thus permitting of its more accurate determination from the films. Figs. 10 (film 200) and 11 (film 201) are characteristic curves obtained in this manner. By scaling the films, it is found that the transformer with an 81-turn secondary has a ratio of transformation 3.2 per cent less

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than the ratio of the turns, and the secondary current leads the primary by an angle of 3.6 deg. These are the constants of the transformer when connected for a ratio of 200 to 1 with a total secondary resistance of 0.94 ohms.

When, however, the transformer is connected for a ratio of 100 to 1, with a 162-turn secondary of 1.32 ohms resistance, the angle of phase displacement and the percentage reduction in the ratio will be approximately $\left(\frac{1}{4} \times \frac{1.32}{0.94}\right)$ or 0.35 of the corresponding

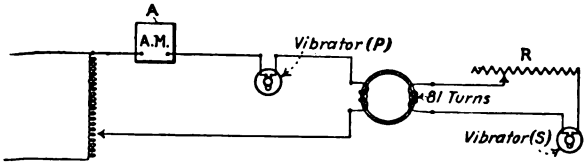


FIG. 9 —CALIBRATION OF CURRENT TRANSFORMER

values for the 81-turn secondary. That is, for the 100 to 1 connection the secondary current leads the primary current by 1.3 deg. and the true ratio of transformation is 1.1 per cent less than the ratio of turns. It should be noted that the only method of obtaining these small corrections is by scaling the films. When dealing with corrections of this order the inaccuracies of the method are such that the above *corrections* may be in error by 25 per cent.

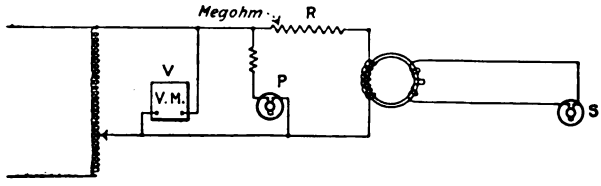


FIG. 12—CALIBRATION OF CURRENT TRANSFORMER

A second method of calibrating the transformer is shown in Fig. 12. In this method a known non-inductive resistance *R* of about one megohm is connected in series with the 16,200-turn primary, and a known voltage, measured by the voltmeter *V*, is impressed across the primary and the megohm resistance. The primary current lags 0.2 deg. behind, or is practically in phase with, the impressed voltage, which is recorded by the vibrator *P*. The secondary current is recorded by the calibrated vibrator *S*. The primary current is computed from the

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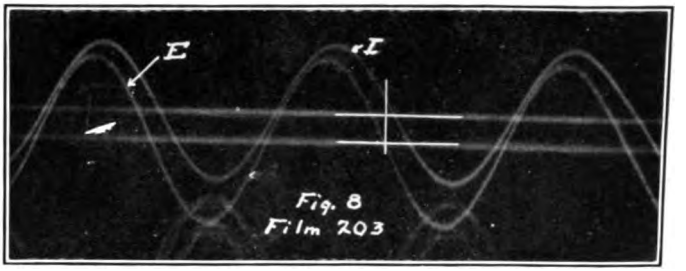


FIG. 8 [BENNETT]

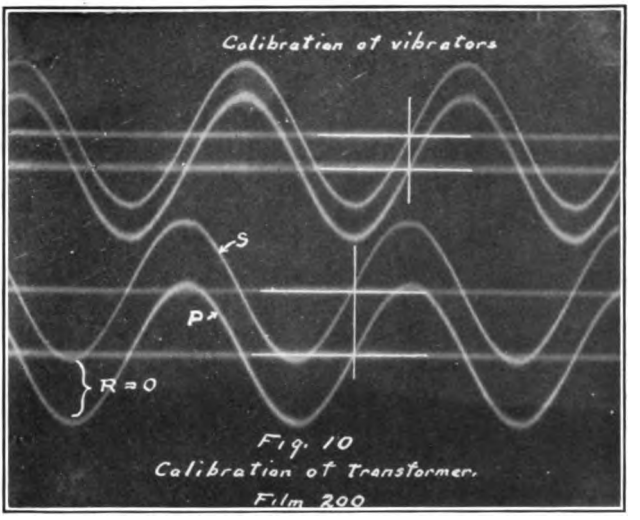


FIG. 10 [BENNETT]

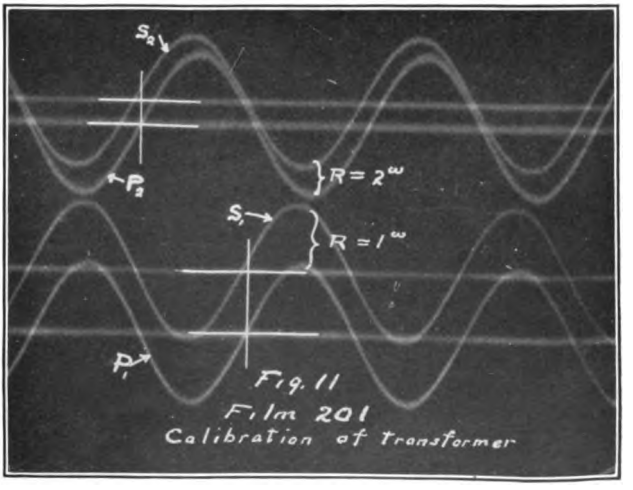


FIG. 11 [BENNETT]

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impressed voltage and the known resistance, while the current in the secondary is obtained by scaling the oscillograms. A number of calibrations made in this manner confirm the results obtained with the Fig. 9 connections.

*Constants of the Transformer for Higher Harmonics.* The constants of the transformer have been experimentally determined only at 60 cycles. From these tests conclusions may be drawn as to the performance for a limited range of higher frequencies.

In the following table is listed the computed values of the secondary reactance and of the secondary impedance to the fundamental frequency, (60 cycles), and some of the higher harmonics. The fourth column of the table shows the relative flux densities required to drive the same secondary current through these impedances at the corresponding frequencies; the fifth column shows the relative values of the eddy currents, and the sixth the relative values of the hysteresis losses.

| Harmonic | Secondary reactance Ohms | Secondary impedance Ohms | Relative flux density | Relative value of eddy currents | Relative hysteresis loss |
|---|---|---|---|---|---|
| 1st (60 cycles) | 0.21 | 1.33 | 1.00 | 1.0 | 1.0 |
| 3rd | 0.63 | 1.46 | 0.37 | 1.1 | 0.7 |
| 5th | 1.02 | 1.67 | 0.25 | 1.3 | 0.5 |
| 7th | 1.47 | 1.97 | 0.21 | 1.5 | 0.6 |
| 9th | 1.89 | 2.30 | 0.19 | 1.7 | 0.6 |
| 15th | 3.16 | 3.43 | 0.17 | 2.5 | 0.9 |

An inspection of this table in connection with the vector diagram, Fig. 5, indicates that,

a. The angle of lead of the secondary current and the discrepancy between transformer ratio and ratio of turns, may be expected to become smaller and smaller for the third, fifth and seventh harmonic.

b. The angle of lead of the secondary current will pass through zero and become an angle of lag, between the fifth and ninth harmonic.

c. The constants of the transformers for all harmonics up to the fifteenth will be extremely satisfactory.

*Displacement Currents.* There remains to be considered the possible transformer errors resulting from the passage of primary current through the transformer as a displacement current from turn to turn or layer to layer. For the purpose of deter-

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mining the order of magnitude of this current, assume the primary is wound evenly in layers, each layer starting from the same side of the spool. With a wall thickness of 0.008 mm. of enamel insulation surrounding each wire, the estimated capacity between adjacent layers is less than $8 \times 10^{-9}$ farads, or the capacity reactance to 60 cycles is 340,000 ohms. With 0.0005 ampere in the primary the voltage between layers is 0.13 volt and the displacement current between layers will be $4 \times 10^{-7}$ ampere or 0.08 per cent of load current.

The first two transformers constructed were wound with 40,000 turns (5 miles) of primary coils of 0.08-mm. enameled wire. For these transformers the displacement current between layers, computed under the assumption of uniform layers, was 0.2 per cent of the load current. This seemed low enough, and accordingly the transformers were wound with no additional insulation between layers. As noted in the introduction, these transformers were designed for a ratio of approximately 100, but on test developed a ratio of only 89; moreover, higher harmonics were not faithfully reproduced in the secondary. For some time the cause of this discrepancy between computed performance and performance on test could not be discovered. Finally, in unwinding one of the transformers the observation was made that the $n$th turn was not always adjacent to the $(n+200\text{th})$ and $(n-200\text{th})$ in the preceding and following layers,—as would be the case with uniform layers, and as assumed in the computations,—but occasionally came in contact with turns farther removed from it, as the $(n \pm 900\text{th})$ or the $(n \pm 1400\text{th})$. The explanation of this is as follows:

In winding a fine wire the turns have a decided tendency to override and " pile up " several turns deep at some parts of the layer, and to run ahead of the correct position at other parts. Where the wire runs ahead of its correct position, a portion of the lower layer is left uncovered, with the result that turns in the neighborhood of the $(n \pm 900\text{th})$ or $(n \pm 1400\text{th})$ turn may come in contact with these uncovered portions of the lower layers. The difficulty of winding in absolutely uniform layers is so great that the wire was allowed to pile up and run ahead in this manner. After observing this condition of the winding it became evident that the loss in primary ampere turns might be far higher than the 0.2 per cent computed for uniform layers; this loss in ampere turns would be due to the " bridging " of sections of the winding at considerable difference

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of potential by the capacity between the turns in contact. The displacement current between these sections in contact would be shunted from the portion of the winding between the turns.

The use of paper insulation between layers is a remedy which immediately presents itself. A layer of paper between each layer of wire would result in a primary coil with a much larger mean diameter. This in turn means a very appreciable and objectionable increase in the leakage reactance.

The primary of the transformer described in this paper was accordingly wound in sections of about 600 turns each, with paper insulation between the sections only. Each section was the full width of the coil and on the average three turns deep. The winding of a section started at one face of the spool, advanced toward the other face, the turns piling up two to four deep all along, and terminated when the other face of the spool was reached. A single thickness of 0.04 mm. tissue paper was wrapped around the completed section, and the next section was wound on this paper, and so on. Wound in this manner, there is no possibility of the $n$th turn coming in direct contact with a turn any farther removed from it than the ($n \pm 50$th). By winding and insulating the transformer in the manner described, it is estimated that the integrated effect of the 60-cycle current shunted from the primary winding has been reduced to less than 0.02 per cent of the total primary ampere turns.

The importance of reducing the shunting effect of capacity between layers to this low value at 60 cycles, is realized when considering the magnitude of the effect for the higher harmonics, for example, the fifteenth. The capacity reactance between turns, layers and sections to the 15th harmonic is 1/15 of the reactance to 60 cycles; the impedance to the passage through the windings of the 15th harmonic in the current is approximately five times the impedance to 60 cycles; therefore, the percentage of the 15th harmonic shunted from the windings will be 75 times the percentage of the fundamental shunted.

If, then, less than 0.02 per cent of the 60-cycle current is shunted from the windings, the percentage of the 15th harmonic will be less than 1.5 per cent. The conclusion is that the influence of displacement currents within the primary winding may be neglected for the fundamental and any harmonic not higher than the 15th.

To check the preceding conclusions relating to higher harmonics in the current wave form, an oscillogram, Fig. 14,

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(film 194) was taken with the connections shown in Fig. 15. In Fig. 15, $B$ is a Leyden jar condenser having about 100 times the capacity of the condenser $C$, which consists of two concentric cylinders separated by air,—a steel wire 0.059 cm. in diameter in a 518-cm. length of pipe of 20.6 cm. diameter. Both condensers in parallel were connected across a high tension transformer generating 9.6 kv. The charging current of the Leyden jars $B$ was sent through the vibrator $P$ and the charging current of the cylinder condenser $C$ was sent through the primary of the current transformer, the secondary being connected to the vibrator $S$. The vibrator $E$ shows the potential wave form across the primary of the transformer. The charging current of the two condensers $B$ and $C$ should have the same wave form, and any appreciable errors introduced by the transformer should cause an appreciable difference in

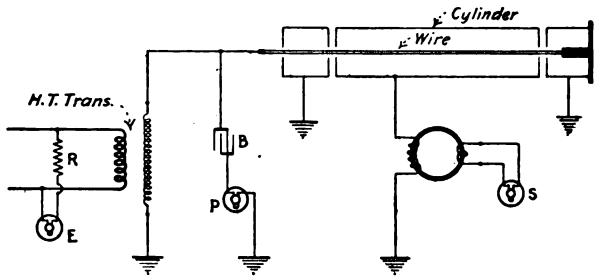


FIG. 15—CONNECTIONS TO SHOW THE REPRODUCTION OF HARMONICS

the shape of the current wave forms $P$ and $S$. An examination of the oscillogram shows that the harmonics in the primary of the transformer are very faithfully reproduced in the secondary.

## V. APPLICATIONS

The transformer extends the field of usefulness of the oscillograph by increasing a hundred fold its current sensitiveness or sensibility. This makes it possible to use the oscillograph in fields from which it has hitherto been barred by reason of the minuteness of the currents to be studied. In this connection, however, it should be recalled that a current transformer cannot increase the watt sensibility of the oscillograph, and that the actual watt sensibility of the combined current transformer and oscillograph is thirty per cent of the watt sensibility of the oscillograph alone. Consequently, the current trans-

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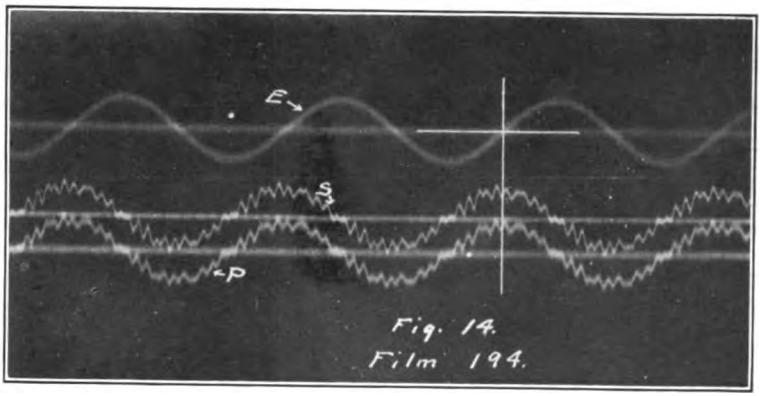


FIG. 14 [BENNETT

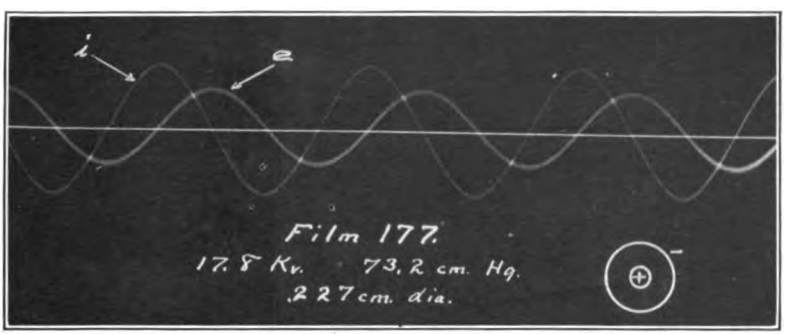


FIG. 17 [BENNETT]

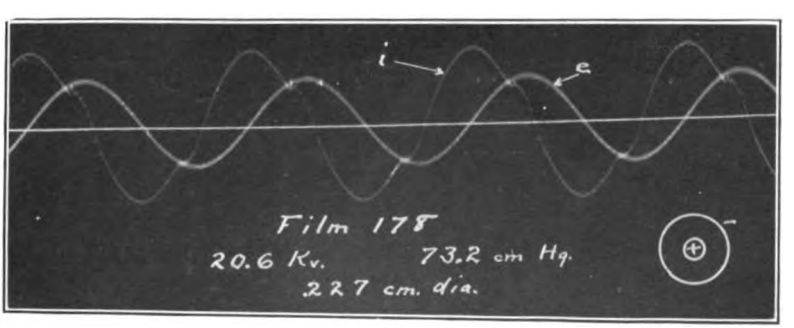


FIG. 18 [BENNETT

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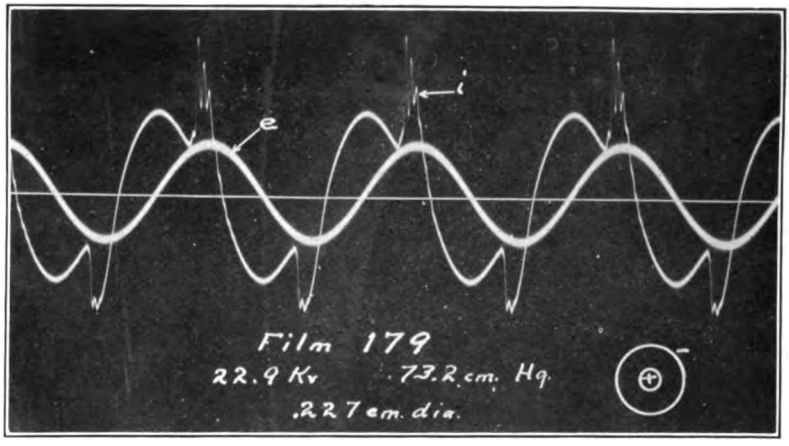


FIG. 19 [BENNETT]

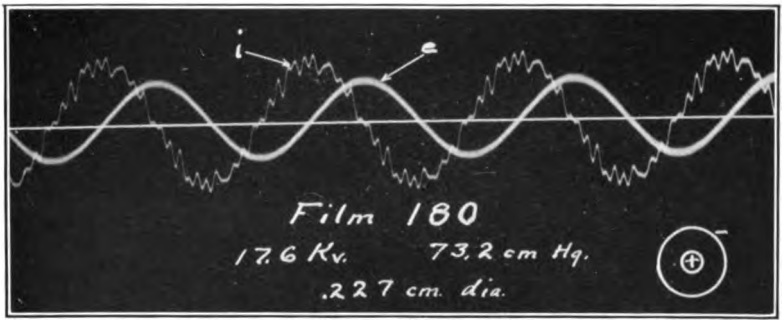


FIG. 20 [BENNETT]

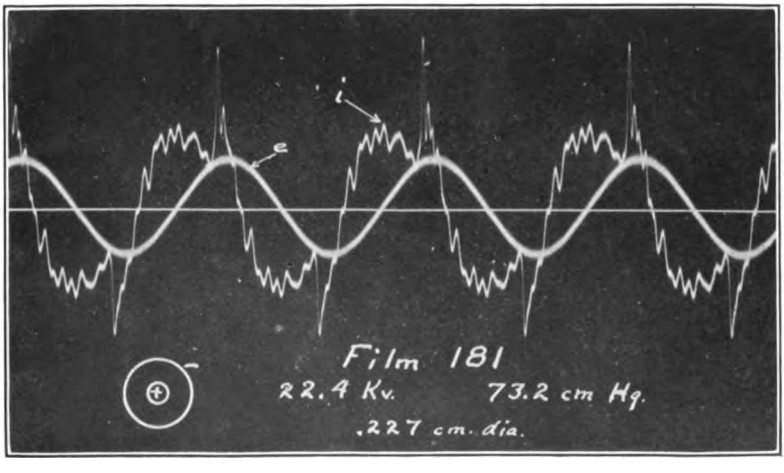


FIG. 21 [BENNETT]

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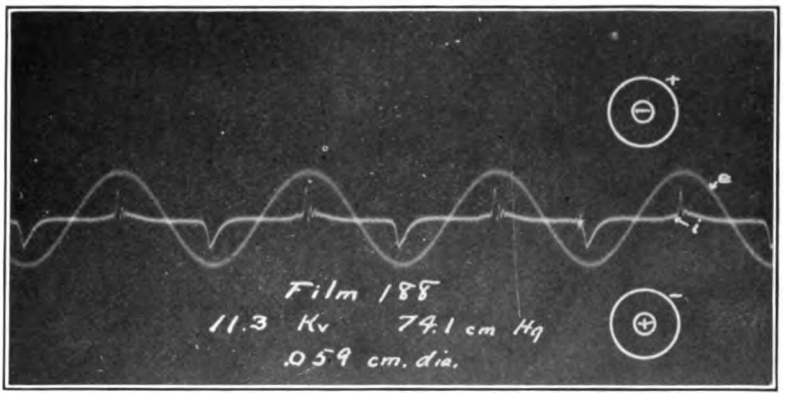


FIG. 22 [BENNETT]

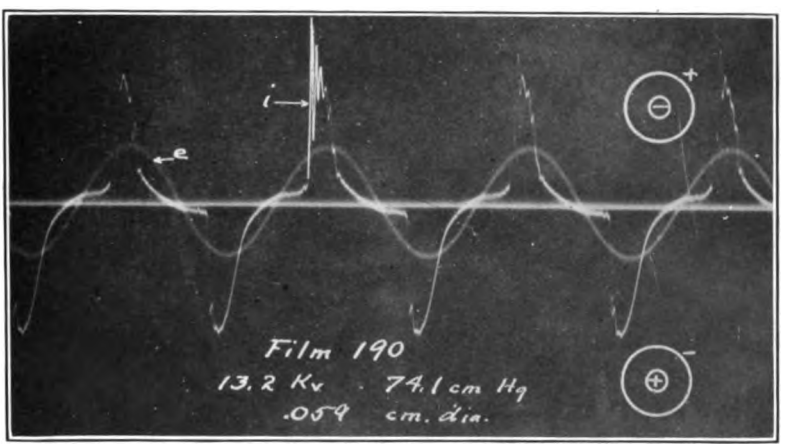


FIG. 23 [BENNETT]

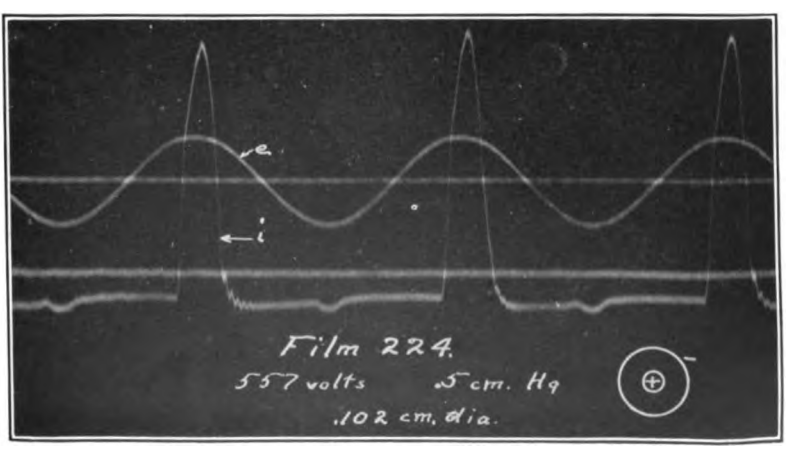


FIG. 24 [BENNETT]

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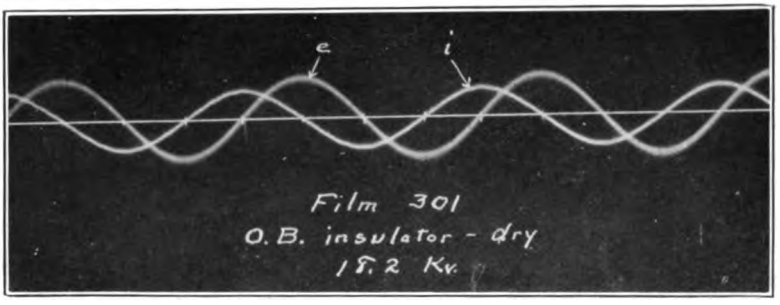


FIG. 25 [BENNETT]

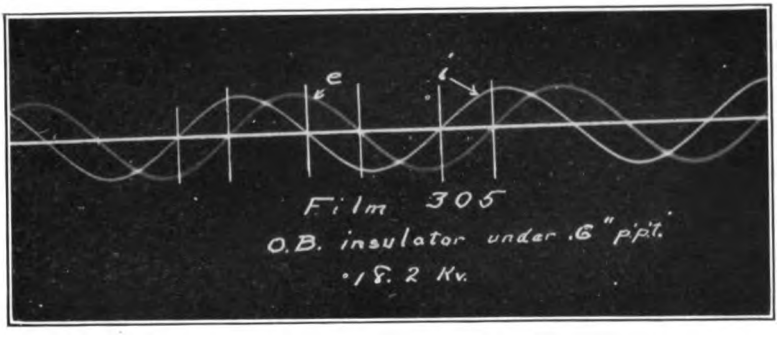


FIG. 26 [BENNETT]

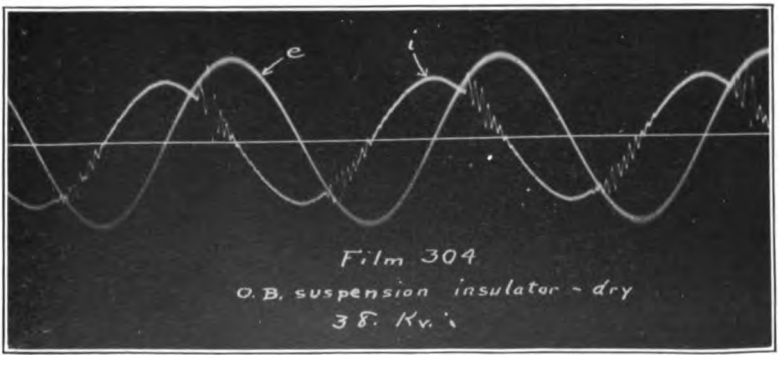


FIG. 27 [BENNETT]

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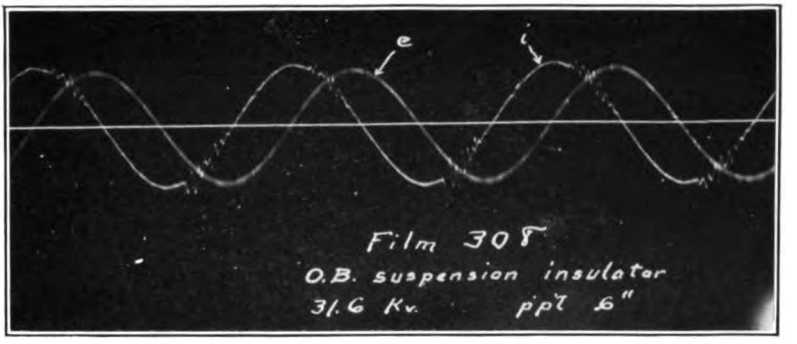


FIG. 28 [BENNETT

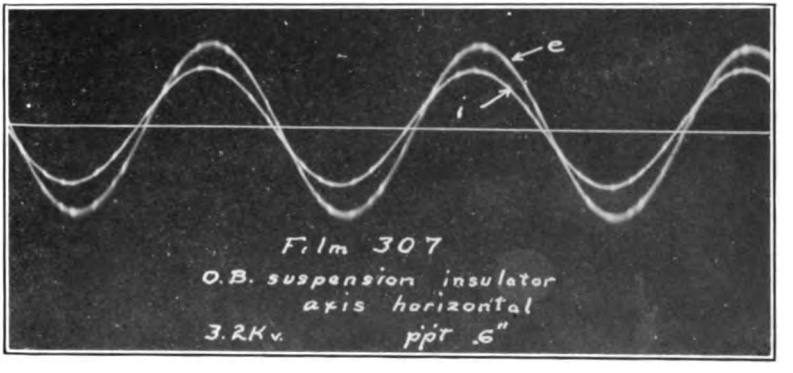


FIG. 29 [BENNETT]

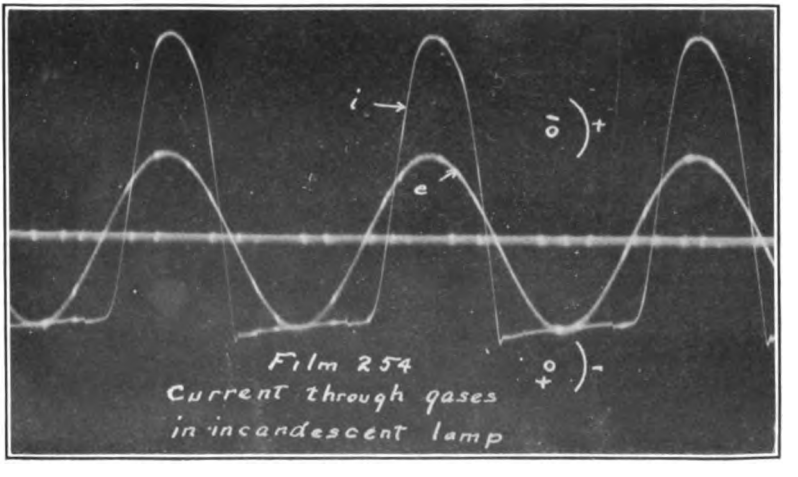


FIG. 30 [BENNETT]

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former can only be used where the current to be investigated flows under a voltage high as compared with the voltage consumed in the transformer. This voltage is of the order of ten volts for 0.0005 ampere. Figures 17 to 30 are oscillograms intended to show some of the applications of the combined current transformer and oscillograph.

*Application to Corona Studies.* The oscillograms, Fig. 17 to Fig. 21, (film 177 to 181), taken with the connections shown in Fig. 2, show the effect of corona formation on the charging current of a wire. The metal cylinder of Fig. 2 was an 8-in. (20.6-cm.) iron pipe 17 ft. (518 cm.) long, in the center of which was stretched a polished copper wire having a diameter of 0.227 cm. Corona is visible around this wire at 18.7 kv.

Fig. 17 (film 177) was taken at 17.8 kv.—below the voltage at which corona is visible.

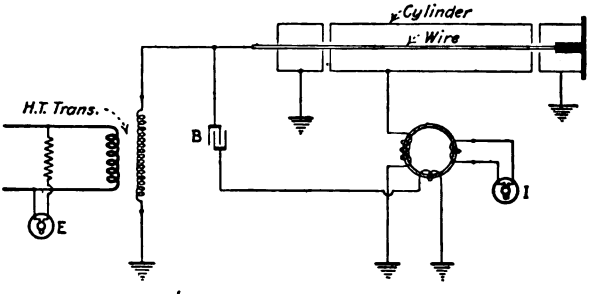


FIG. 16

Figs. 18 and 19 (films 178 and 179), were taken above the corona voltage at the voltages indicated on the films. They show: (a) the point on the e.m.f. wave form at which copious ionization sets in, (b) the duration of the period of ionization, (c) the asymmetrical nature of the process of breakdown. In all these films a positive current is a current from the pipe to the wire, or the wire is cathode for positive deflections.

The three films above referred to were taken with a combination of inductance and capacity in the circuit adjusted to "weed out" all harmonics from the generator wave form. The next two oscillograms, Figs. 20 and 21 (films 180 and 181), were taken with the same wire but without "weeding out" the harmonics from the impressed voltage.

To show more clearly the characteristics of the current which flows when corona forms, the connections shown in Fig. 16 may be used. In Fig. 16, the charging current from a con-

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denser $B$, connected between wire and ground, is sent through one of the secondary coils of the current transformer is such a direction as to oppose the magnetomotive force of the primary current.

The capacity of the condenser $B$ is adjusted so that its charging current neutralizes the charging current between wire and pipe for all voltages below the formation of corona. When corona forms the two currents no longer balance, and the deflection of the current vibrator shows the current which is superimposed on the charging current as the result of the ionization. Figs. 22 and 23 (films 188 and 189), were taken with Fig. 16 connections, with a 0.059-cm. steel wire in the 8-in. pipe.

The asymmetrical nature of the current is more striking at low gas pressures than at atmospheric pressure. This is in-

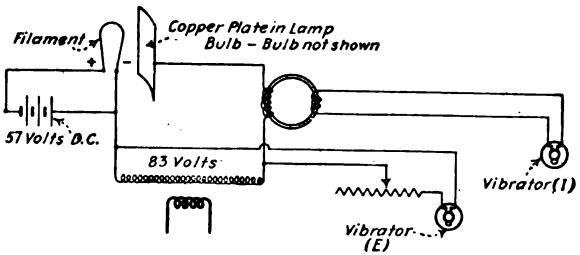


FIG. 31

dicated in Fig. 24, (film 224), an oscillogram obtained with a 0.102-cm. phosphor bronze wire in the 8-in. pipe of Fig. 2.

This oscillogram was obtained with the pipe closed at the ends and exhausted to a pressure of 0.5 cm. of mercury.

*Application to Insulator Investigations.* The current transformer may be used to determine the charging and leakage currents of high-tension insulators and the ohmic resistance of wooden pins at high voltages.

With the connections shown in Fig. 1 the oscillograms in Figs. 25 to 29 were taken on a 10-in. (25.4-cm.) suspension insulator.

Figs. 25 and 26 (films 301 and 305) were taken at 18.2 kv. with the insulator dry and under spray respectively. The spray was directed downward at an angle of 45 deg. from the vertical; the rate of precipitation was 0.6 in. (1.5 cm.) per minute. The 60 cycle charging current of the dry insulator at the rated voltage, eight kv., is $2.16 \times 10^{-4}$ (r. m. s.) amperes indicating a capacity of $3.14 \times 10^{-11}$ farads. Under spray,

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Fig. 26, the current leads the potential by only 70 deg., or the resistance of the insulator drops to 180 megohms.

Figures 27 and 28 (films 304 and 308) show the charging current at a voltage high enough to cause streamers over a part of the insulator surface. The oscillograms were taken with the insulator dry at 38 kv. and under spray at 31.6 kv. repectively. For positive currents the insulator pin is cathode and the metal cap is anode.

Fig. 29 (film 307) is an oscillogram taken on a 10-in. (25.4-cm.) suspension insulator under spray, with the axis of the insulator horizontal. The insulator resistance is only seven megohms.

*Application to the Study of Conduction in Gases.* The transformer may be used to determine the wave form of the minute leakage currents between electrodes in gases at low pressures.

Fig. 30 (film 254) shows the wave form of the current through the gas between an incandescent carbon filament and a copper plate mounted in the evacuated bulb of an incandescent lamp.

The filament was a 55-volt 16-c.p. filament, operated at 57 volts on direct current. A 60-cycle alternating voltage of 83 r.m.s. volts was impressed between the copper plate and one terminal of the filament; the connections are as shown in Fig. 31. In interpreting this oscillogram, it should be recalled that the average value of the current delivered by the secondary of the current transformer will be zero, irrespective of the wave form of the primary current. The negative branch of the current wave does not mean that the primary current flows from the incandescent filament anode to the copper plate cathode. The primary current is unidirectional and only flows during the half cycle in which the filament is cathode. No appreciable current flows when the cold copper plate is negative to the filament; the current shown by the oscillogram during this half cycle is only an apparent current; it is due to the shift of the secondary current wave form with reference to the primary current wave. Both wave forms are similar, but the primary is unidirectional while average of the secondary must equal zero.

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*To be presented at the 293d Meeting of the American Institute of Electrical Engineers, Pittsburgh, Pa., April 10, 1914, under the auspices of the Committee on the Use of Electricity in Mines.*

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(*Subject to final revision for the Transactions.*)

# MINE SUBSTATIONS–I
## Their Construction and Operation

BY H. BOOKER

ABSTRACT OF PAPER

The use of electricity in mines has been making rapid progress throughout the United States. Steam and compressed air are being superseded largely by central station power. Power from a central station requires a substation to supply direct current to operate locomotives, cutting machines, etc. A substation is used to transform high-voltage a-c. power to direct current at 250 or 500 volts.

Substations, when possible, should be located on the surface, because if located underground there is danger from fire, and dampness weakens insulation and causes corrosion of metallic parts. Construction of an underground substation is more costly than on the surface, as there is danger of the roof giving way. The roof should be arched, or built of heavy concrete and the whole station made fireproof.

When substations are located underground it is necessary to carry a high-tension cable through bore-holes. When located on the surface a low-tension cable can be used.

Many accidents occur because of incompetent men. Good salaries should be paid and competent men obtained. Danger warnings should be posted and men taught to consider wires as being " live ", thereby lessening accidents.

DURING the last few years the use of electricity in mines has attracted a great deal of attention throughout the United States. This is largely due to the large increase in coal consumption making it necessary to discard the early primitive methods of running and to install modern power equipment, without which it would be impossible to produce the required output with the present supply of labor.

Steam and compressed air have been and are still used to a large extent for the power supply at the coal mines, but there is a growing use of electricity especially during the last two or three years, due to the introduction of central station power which, strange to say, can be sold to a coal mine cheaper than the mine can produce it itself.

The greatest care should be exercised in the introduction of electric power in a coal mine and the very best advice should



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be obtained before attempting any electrical installation about a mine. Electric power improperly installed and not properly operated and maintained will no doubt prove a hazard and it is just such conditions that is causing apprehension in some localities regarding the use of electric power in mines.

The danger and unsatisfactory service associated with electric power in the past, has been largely due to the short sighted policy of the coal mining companies in purchasing cheap equipment unsuited to the service and in employing incompetent labor.

A coal mine is the last place where inferior or poorly designed electrical apparatus should be used, as the risk of trouble is too great.

Even with the best designed and best adapted equipment the question of operation and maintenance is one that is often sadly neglected. The matter of compensation is often allowed to play too prominent a part, and the wages offered are such that it is impossible to obtain competent men who will take proper care of the equipment and who will realize the importance of properly maintaining the apparatus.

Rigid, systematic, and careful tests should be made periodically on all moving parts of electrical equipment to insure proper operation and records kept of these tests for future reference.

Warnings regarding the danger of touching wires cables or electrical apparatus should be from time to time pointed out to all workmen in the mine, and in some way kept constantly before them. The primary cause of the majority of accidents, it is fair to say, is partial or complete ignorance. Those unskilled in electrical work should treat all electrical apparatus as alive, as only in so doing lies complete security for them.

The writer proposes to deal with the installation, operation and maintenance of substations around coal mines from the standpoint of the practical operator. Until quite recently the electric power in use at coal mines was produced by small isolated plants located at each mine. With the large increase in production and the combination of many small mines, the central plant idea and the purchase of central station power is rapidly gaining ground.

The use of power from a central plant, or of purchased power, requires a substation to supply direct current to operate the mine locomotives, cutting machines, underground pumps and lights.

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A mine substation, in general, consists of one or more motor-generator sets or synchronous converters used to transform high voltage a-c. power to direct current at 250 or 500 volts.

The small isolated plant was generally placed near the pit mouth, provided the coal and water supply was convenient. As the capacity of the mine increased and the distance to the working face became greater the power conditions became quite unsatisfactory. An increase in the capacity of the existing plant often means a large expenditure of time and money so that the purchase of central station power and the installation of a substation offers the best solution. The substation can generally be placed at a more advantageous point than the isolated plant since a substation is independent of coal and water supply. An increase in power supply at any time can be easily and quickly taken care of at a low cost.

Substations when properly designed and installed require little attention, and the attendant is needed only to reset circuit breakers and to see that everything is running properly. If power is not wanted the machines can be cut out and all expense for current stopped. Starting up is a simple matter of closing a switch and full power is available immediately.

With purchased power, the substation system of power distribution is most advantageous for coal companies operating singly or widely separated mines. The operator transfers his responsibility to those whose business it is to carry it, leaving him free to his business of mining coal, thus relieving him of the worry and care of his power plant, and thereby greatly increasing the efficiency of his coal mining department. The operator substitutes his power house with its engineers and firemen and its need for good and abundant water, with a small substation that requires only one attendant and no water supply.

The exact location of the substation is often a hard question to decide. Conditions frequently arise where it would be desirable to install the substation underground, but in general, unless absolutely necessary, the substation should be placed above ground. The preferable location is at the pit mouth when possible, as it can then be looked after by a workman who has other duties to perform. In a small mine the tipple foreman can attend to the station, while in a shaft mine the station should be located in the hoist room and looked after by the hoist engineer. In a large mine requiring more than

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one station, they should be located centrally to the work to save the expense of heavy copper feeders. The substation can often be located near the fan so that the same operator can look after both. When the d-c. feed wires cannot be carried into the mine by one of the openings, bore holes can be used, as it is comparatively simple to maintain a 500-volt cable installed in a bore hole.

In regard to locating the substation underground there are many objections to this. Beside the source of danger from fire there is most always considerable dampness underground which not only weakens the insulation but causes corrosion of unprotected metallic parts. It is practically impossible to make an underground substation free from moisture, and good ventilation is often difficult to obtain. This matter of ventilation is very important as the heat losses in the apparatus must be carried away so that the capacity of the machines will not be impaired. This question will be readily appreciated when it is considered that one kilowatt loss per minute is equal to 57 B.t.u. which is equivalent to heating about 3001 cu. ft. (84 cu. m.) of air one degree fahr. per minute. The total loss in a 200-kw. station will be approximately 15 kw. The heat generated will, however, help to keep the substation dry in conjunction with proper drainage and pumping.

All underground substations should be ventilated with intake air and all high-tension cables should, when possible, be carried to the substation in the intake airway. This may work a hardship particularly if the mine is shaft operated and a blowing fan is used, as it is practically impossible to maintain wires in a shaft of this kind on account of the high air velocity. The writer knows of mines of this type where it is unsafe for a man to attempt to ascend the stairway, much less do any work while the fan is in operation.

Very often considerable coal dust and pure sand is picked up by the air currents which is a rather severe matter, as the dust and sand plays havoc with the bearings and oiling systems.

A very important point regarding the construction of an underground substation is the cost of construction, which is considerably greater than building on the surface. Since there is always danger of the roof giving way, the roof should be arched or built of heavy reinforced concrete and the whole station made fire proof. For a 200-kw. substation the dimensions should not be less than 24 by 24 by 12 ft. (7.3 by 7.3 by 3.6 m.) high.

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With the substation located underground it is generally necessary to carry a high-tension cable through a bore hole. With the station located on the surface this cable will be a low-tension cable and there will be no trouble to maintain it. A satisfactory method is to use "lead" covered cable attached to a messenger cable about every 30 feet by wiped joint or suitable clamps which will not injure the lead. The high-tension cable is much more difficult to maintain, and most mine electricians know what it means to maintain high-tension insulated cable in deep shafts and in bore holes.

The question of attendance for an underground substation is a serious one and actual experience has taught the writer that it is impossible to get men underground to give machinery the same attention they will give it on the surface. This is particularly true of the night shift, as it has been found that there is a greater tendency among men to sleep on the night shift in mines, than on the same shift outside. This may be due to the mine atmosphere which is often contaminated with gas from gob workings.

In regard to the general design and construction of a mine substation, space economy should be given consideration, but care must be exercised to see that there is plenty of room for making repairs and replacements.

The operating requirements of a substation in regard to continuous service may vary from a few hours per day to practically continuous service. As due provision must be made for inspection and repairs it is quite evident that in case of continuous operation, attention must be given to the proper sectionalization of the apparatus and duplication of the equipment.

A very important point to consider is the relative attention that will be given to the operation of its station by the consumer and the central station company. It is only natural that the consumer will want to supervise the operation of his own station so that it is evident that any complications in switching equipment and control apparatus should be avoided.

The substation should be constructed of fireproof material, and all high-voltage apparatus should be enclosed to secure maximum safety to attendants. Asbestos lumber should be used for partitions and doors, which serves as a protection against shock and is a valuable protection in case of fire.

The common faults in electrical installations of this kind are as follows:

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Exposure of high and medium pressure conductors at the surface and high and medium pressure switching gear underground.

The frames of high and medium pressure apparatus not properly grounded. All machine frames should be well grounded.

Switches, cables, rheostats, starting boxes, etc., mounted on wood and surrounded by as much wood as possible, the whole often resulting in two occurrences; first, a shock by coming in contact with an exposed live part; second, fire due to defective joints in cables.

Omission of tubes, where frames of machines and brattices are pierced by cables.

The common defects of organization are as follows:

The absence of trained electricians.

The handling of live wires or apparatus for adjustment or repair when not absolutely necessary.

The absence of a definite and distinct rule that unskilled men may handle electrical cables and apparatus only when the power is off.

The use of central station power will no doubt bring the operating force at the mine in close touch with the central station operating force which is always ready and willing to advise the coal operator in regard to his installation and operation.

It is to be hoped that improved legislation and a better cooperation between the mining companies and the Bureau of Mines will greatly increase the safety and improve the operating conditions in connection with the use of electricity in mines.

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# MINE SUBSTATIONS—II
## Motor-Generator Sets vs. Synchronous Converters

BY WILL M. HOEN

ABSTRACT OF PAPER

The number of mines which use electrical power supplied by transmission lines carrying high-voltage alternating current is constantly increasing. Low-voltage direct current is usually required for underground work in all coal mines. These conditions require the installation of motor-generators or synchronous converters. The extent and location of the mine workings will determine the voltage of the direct-current supply. Improper application of the transforming apparatus may result in great variation of voltage in the direct-current network, with its attendant disadvantages.

The operating characteristics of the induction and synchronous motor-generator sets and synchronous converters are considered with regard to starting conditions, d-c. regulation and the effect on the a-c. transmission lines, a-c. voltage regulation, and power factor correction.

Mine conditions and the nature of the power supply will determine the type of transforming apparatus which will give the most efficient and satisfactory operating conditions. Each of the several types of apparatus has a field where the best results will be obtained.

DURING the past few years there has been a great increase in the number of mines, especially coal mines, using power supplied from the mining company's central power plant, or by central stations. Several central stations have recently built, and others have greatly extended their distribution, with the main object of serving mining districts. These conditions are making economical power possible for all kinds of mines. To provide economical transmission, this power is generally distributed at a voltage which requires transformation before it can be utilized in rotating machinery. Operating conditions at the average mine are such that direct current is required, and this requires the installation, as part of the mine equipment, of a motor-generator set, or a synchronous converter. The object of this paper is to show the adaptability and field of each type as applied to mine service.

In the small coal mine, where power for haulage service will



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be a chief requirement, it is generally necessary, because of the mine location and layout, to feed power from the extreme end of the feeder system. Under these conditions, to avoid installing an excessive amount of copper and in order to maintain a reasonable voltage in the region of the maximum load, an increase in the terminal voltage of the d-c. generator becomes necessary with the increase in load.

However, when the mine workings become extensive, the low voltage generally used makes it desirable to feed into the feeder system at its load center, or even into two or more such places. This is sometimes accomplished by installing a substation underground, or in shallow mines, which are in favorable locations, on the surface, feeding the low-voltage current underground through boreholes. Under these conditions, an economical feeder system can be installed, so that the drop is low, and an increase of terminal voltage with an increase in load is not so necessary or desirable. As the mine system becomes larger, the amount and size of the apparatus will increase so that motors in constant load service, such as pumps and mining machines, will be distributed throughout the mine, to whose successful operation an excessive variation of voltage will be detrimental.

A direct-current motor, when subjected to an excessive increase in voltage, will have its shunt coils overheated, and its speed will increase, which will, with certain characteristic loads, overload the motor.

An excessive reduction in voltage will cause over-heating of the armature, reduced speed and reduced output. Series motors are generally used for intermittent service, and, as the torque is a function of the current, lower voltage will mean a greatly reduced speed and an increase in the time for any particular cycle of operation. This will invariably result in overheating of the motor windings.

Power for mine service is nearly always purchased on a unit basis and is easily and accurately measured. The actual cost of power is, therefore, accurately known, which is quite different from the former conditions, where each mine was usually served by an individual power plant where the actual cost of power was very indefinite. Due to the ease of ascertaining the actual cost, the mine operator is vitally interested in the overall efficiency of the transforming apparatus.

The average mine is served with three-phase, 60-cycle power, at a voltage which is rarely higher than 11,000. Expert at-

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tendance is not available or desirable. The first cost must be kept at a minimum, with the operating efficiency at a maximum. Direct current is required at a voltage generally under 300, but never exceeding 550. The selection of the proper apparatus lies between a motor-generator set, of the induction or synchronous type, and a synchronous converter. The starting characteristics of the last two types of machines have been very greatly improved, and the operation of the starting greatly simplified, within the last few years. The starting conditions of these machines in the order of their desirability follow:

1. Induction motor-generator.
2. Synchronous motor-generator.
3. Synchronous converter.

The induction and synchronous motor-generator sets consist of two machines, a motor and a generator, each electrically and magnetically independent. The generator can be given any reasonable characteristics, but standard practise is to flat-compound for 500 or 250 volts, or to over-compound not to exceed 10 per cent. The operating characteristics of the direct-current generator are understood by the average mine attendant, as its operation is similar to engine-driven generators with which he may be familiar.

The induction motor-generator set is exceedingly easy to start, but has the disadvantage of a small air gap and a lagging current characteristic, which causes the transmission line to carry an additional current above the required load current. This means an increase in the transmission line and power station generator capacity.

The synchronous motor-generator set of the present day is no more difficult to start than the induction motor set. It has the advantage of a large air gap and the power factor of the machine is under the control of the operator. This latter feature, if properly applied, is of great benefit to the transmission line regulation. If induction motors are in use at the same mine, operating the synchronous motor at a leading power factor will greatly offset the lagging wattless component. It requires judgment to secure the best results from this feature. While the corrective effects apparently only benefit the power company, they may be detrimental as well as beneficial, and in order that the power company may secure the greatest benefit, it would be necessary for the attendant to be under the control of the power company, as far as power factor adjustment is

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concerned. Standard machines are usually built for operating at unity power factor at full load, and under average load conditions it is possible to operate them at slightly leading power factor without detrimental results.

It is now recognized that a low power factor load is detrimental to the power company, so that such loads are sometimes penalized, the power rate being based on the power factor. Under such conditions it is advisable for the mine operator to utilize the corrective effect of a synchronous machine, so as to offset the lagging effect of any induction motors. It is not always economical to attempt to raise the power factor too high, as the corrective effect obtained from a given wattless component is much less in the regions of unity power factor than elsewhere. Generally speaking a power factor of 90 per cent would be considered good. The efficiency of a synchronous motor will be materially affected

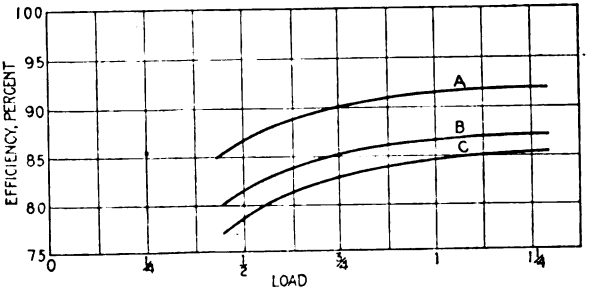


FIG. 1

by over-excitation. Reference to Fig. 1 will show the efficiency curve of a standard synchronous motor-generator set, as built by one manufacturer, when operating at unity and 80 per cent leading power factor.

Synchronous converters are nearly always started from the alternating-current end, and are no more difficult to start than in the preceding cases, except that it is necessary to close the field break-up switch, so that the direct-current polarity will be correct. They have the advantage of large air gaps, and each unit consists of one machine instead of two. The machine itself is much lighter, and requires less energy to bring it up to speed. The 60-cycle converter of today is quite a different piece of apparatus from that of only a few years ago.

Referring again to Fig. 1, curve *A* is the efficiency curve of a standard synchronous converter of the same rating as the motor-

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generator set, with transformer losses included. A converter does not lend itself to power factor correction to the same extent as the synchronous motor. The disadvantage of using transformers will be offset by giving the machine a large decree of protection from grounds which might be caused by surges on the high-tension line. It is much easier to run, temporarily, on two transformers than to repair a high-voltage coil in either an induction or a synchronous motor.

A synchronous converter necessarily requires transformers, while both the induction and synchronous motors can be wound for moderately high voltages. Standard mine sets of less than 300 kw. are not wound for voltages in excess of 2200. Therefore, if the voltage is above 2200 transformers will be required in either case, or the machine can sometimes be wound for a higher voltage at an increased cost and reduced efficiency.

In contrast to a motor-generator set, the alternating-current and direct-current sides of a synchronous converter are connected together. The direct-current voltage bears an approximately constant ratio to the impressed alternating-current voltage. In a direct current generator, an increase in voltage with an increase in load is obtained by placing series coils on the field poles, which coils carry all or a portion of the load current. In the converter the same method is used, but the accompanying results are obtained quite differently. Standard synchronous converters are built so as to give flat compounding, maintaining approximately constant terminal voltage. As the direct-current voltage bears a definite ratio to the alternating-current voltage, it is necessary to maintain constant voltage at the collector rings. This is accomplished by having a suitable reactance and a certain minimum resistance in the alternating-current circuit. This reactance may be introduced separately or be in the transformer, line and generator. To maintain constant voltage, the line drop, due to resistance, must not be in excess of 10 per cent. Maintaining constant voltage with varying load by changing the series field excitation will change the power factor. The effect on the line, therefore, is quite different from that caused by a synchronous motor without compounding, as usually built. This results in the difference in corrective effect of the two types of machines. Over-compounded synchronous converters are not standard, because certain limitations peculiar to the type of machine make it undesirable.

In a synchronous converter, part of the alternating current

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passes directly to the direct-current end, without circulating through the entire converter windings. The heating capacity of a direct-current generator will depend upon the average heating, while in a synchronous converter it depends upon the heating of the so-called tap coils. Low power factor at full load will cause heavy currents to circulate in the converter winding. As the tap coils must carry this heavy current in addition to the current passing through them, the heating will be above the average of the rest of the winding.

The average mine load, referring particularly to the direct-current load, is usually of a very fluctuating character. Assuming that the field of a synchronous motor is adjusted for unity power factor, say at $\frac{3}{4}$ load with constant excitation, the power factor will be leading at lighter loads and lagging at the heavier loads. A synchronous converter, as generally constructed with varying excitation caused by compounding, will act quite differently, provided, of course, that the line conditions are suitable. As the load falls below the $\frac{3}{4}$ value, the power factor will be lagging, and at full loads, and overloads, slightly leading. Where power is received at high voltages from large transmission lines, the capacity effect may make it more desirable to have a lagging component at light loads and leading at maximum loads. Under these conditions the synchronous converter will give the most desirable performance. However, where large corrective effects are required there is no doubt but that the synchronous motor is the type to be employed. When the synchronous motor receives its excitation from an over-compounded generator the exciting current will increase with the load, thus tending to hold the power factor up on overloads. The synchronous motor-generator set can be successfully operated on a line whose characteristics are such that the operation of a synchronous converter would be unsuccessful. Parallel operation between machines of the same type is practically on the same basis for each of the three types. Parallel operation between machines of the different types is not advisable, as considerable adjustment will be necessary to obtain equal division of the loads.

*Cost.* A comparison in prices between the induction, or synchronous, motor-generator set, and the synchronous converter, including transformers for the latter, will show that the costs are approximately the same when transformers are not required by the motor-generator set. It is the usual practise for the central station to supply power at 2200 volts, so that it is seldom neces-

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sary for the coal company to purchase transformers. In smaller sizes the synchronous converter with its transformers will cost a little more than the motor-generator set, while with the larger sizes, the reverse is true. For the sizes most common for mine work, the motor-generator set will cost less than the synchronous converter with transformers.

The foregoing comparisons show that where the line characteristics are suitable, the operating efficiency and automatic alternating-current line regulation are in favor of the synchronous converter. Where large corrective effects are required on the alternating-current line, compounding is desired on the direct-current machines, and the transmission line characteristics are not of the best, the synchronous motor will prove the most reliable. When the voltage and frequency variations are such as to preclude the successful operation of synchronous apparatus, the induction motor-generator set should be used.

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# SELF-CONTAINED PORTABLE ELECTRIC MINE LAMPS

BY H. O. SWOBODA

ABSTRACT OF PAPER

The considerable number of mine explosions caused by defects of the Davy safety lamps has encouraged the development of electric lamps. Satisfactory results, however, have been obtained only since the invention of the tungsten lamp, permitting the use of smaller storage batteries.

The general requirements for electric lamps are: absolute safety, uninterrupted production of light for at least one shift, and a foolproof design. Prizes offered by the British Government in 1912 for the best electric lamp, resulted in 197 different constructions being submitted. The first prize was awarded to a German lamp, which since that time has been used with great success all over Europe and which is also being introduced in this country.

The construction of this lamp, consisting of several types for different requirements, and the methods of handling it in actual service, are fully described. Some figures covering repairs and renewals are given.

In concluding, the author mentions the only objection that can be raised against electric portable mine lamps, that they cannot be used as detectors of mine gases, as Davy lamps can, and says that for this purpose devices distinctly separate from the lamp will have to be adopted.

IT IS a well-known fact that a considerable number of mine explosions with their enormous losses of life and property are caused by defects and improper handling of the so-called miner's safety lamps, built on the Davy principle. The Bureau of Mines, for instance, mentions in one of its reports that at least two disasters in this country in 1912 were caused in this manner, killing more than a dozen men, and the Prussian Government states that during the decade from 1902 to 1911 at least 27 per cent of all explosions in the anthracite mines are to be blamed on these lamps. Therefore, it is only natural that attempts to develop a portable *electric* safety lamp were made quite some time ago. Satisfactory results, however, have only been obtained since the carbon filament lamps were superseded by the tungsten lamps. Due to their high economy in current consumption they permit the reduction of the battery to such an extent that the weight and size of the portable lamp does



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not prevent the miner any more from moving around freely in performing his duties.

## General Requirements

Electric safety lamps must answer the following requirements:

Absolute safety against ignition of mine gases;

Uninterrupted production of a steady and sufficient amount of light for at least one shift;

Absolutely foolproof design.

Besides this, it is essential

To have a simple and durable construction;

To keep the weight at a minimum;

To facilitate the charging and inspecting of the battery.

*Safety.* Careful experiments conducted by the Bureau of Mines in Pittsburgh and also at Gelsenkirchen, Germany, have shown that the only source of danger in a portable electric lamp is the glowing filament of the incandescent lamp.

Sparks obtained by the breaking and establishing of the electric circuit are not of sufficient strength to ignite mine gases, due to the low voltage and amperage of the batteries used, as long as the maximum short-circuiting current of these batteries does not exceed

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 100 | amperes | for | batteries | with | not | more | than | 2.5 | volts |
| 85 | " | " | " | " | " | " | " | 4.0 | " |
| 65 | " | " | " | " | " | " | " | 5.0 | " |
| 45 | " | " | " | " | " | " | " | 6.0 | " |

Therefore it is not necessary to provide special protection against sparking on the switch and on the connections between battery and lamp.

As the filament under normal conditions is operated in a vacuum and enclosed in a glass bulb, the danger of igniting mine gases exists only in case this bulb is smashed without the filament being broken at the same time, so that the latter continues to glow until it burns out. Several absolutely safe methods can be employed to prevent the filament from glowing after the bulb has been broken, and one method which has been in actual use for a number of years will be described in the course of the paper.

*Steady and Sufficient Light.* The miners' *old* safety lamps furnish a flickering light of about 0.8 c.p. capacity, which rapidly decreases during the shift to about one-half. This is not sufficient light for the miner to perform his work satisfactorily, and, ac-

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cording to the investigations made by Dr. T. Lister of Llewellyn, England, is the principal cause of the special eyesicknesses (miner's nystagmus) with which miners become affected. For this reason it was considered advisable to equip the *electric* mine lamps with incandescent lamps of at least 1.5 c.p.

The only source of electrical energy which will produce this amount of light satisfactorily for at least one shift or approximately ten to twelve hours is the storage battery, primary batteries for such an output being entirely too large for use in portable equipments. Years of development have resulted in fairly satisfactory batteries and it seems, in the present state of the art, that the lead cell, regardless of its weight, on account of its comparatively high voltage and slow drop in voltage while discharging, is the most suitable type.

*Foolproof Design.* Miners' lamps are exposed to extremely rough handling by inexperienced hands and the least mechanical or electrical weaknesses are liable to result in a failure to supply light. The following are about the most important points which must be observed in a successful lamp:

The lamp must be locked so that the miner absolutely cannot get at any part of the mechanism.

It must burn in any position, even, under water, and if dropped on solid material, such as rocks, iron, or cement from a height of several feet must continue to operate.

The incandescent lamp bulb must be thoroughly protected so that it is almost impossible to break it.

The electrolyte of the battery must not leak out.

That constructions of this character are possible, and in actual use, will be shown later on.

## Lamp Designs

During the year 1912 prizes were offered by the British Government for the best portable electric mine lamp and not less than 197 applicants entered into competition and submitted samples. After careful tests extending over several months, the first prize of $3000 was awarded to the makers of the "Ceag" lamp described in this paper. Since this lamp has also been accepted by practically all other European governments and was the first lamp approved by the Bureau of Mines, answering all requirements, and still remains today the only approved *hand* lamp, it might be well to study its construction carefully.

Fig. 1 gives an idea of the general appearance of the lamp.

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The incandescent lamp is covered by a heavy glass dome, which is protected by four heavy steel rods held together by a sheet steel roof. A substantial hook is attached to this roof, so that the miner can either stand the lamp on the ground or hang it to a post in the immediate neighborhood of his working place. The bottom part, made of heavy corrugated galvanized sheet steel, contains the storage battery. By turning the upper part on the lower, the miner can turn the light on and off.

The construction of the lamp is easily understood from a section shown in Fig. 2.

The incandescent lamp *l* rests in a socket *n*, which is pressed upward by a spiral spring *o* against another spring *p* between the bulb and glass dome *b*, providing a complete spring support and preventing breakage even with the most severe shocks. Electric connection is established for one pole through the socket spring *o*, and for the other pole by another smaller spring *d* inside the socket spring, and insulated from it. In case the bulb breaks, the socket spring pushes the socket upwards, and as the inner spring does not expand as much as the socket spring, the circuit is interrupted.

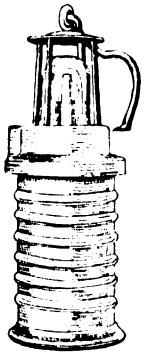

FIG. 1

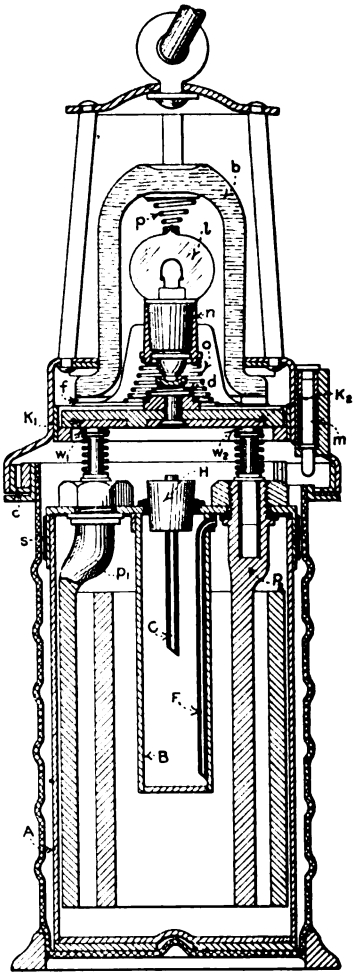


FIG. 2

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Lately, another safety device has been added, but is not shown in this illustration. It consists of a fuse, which blows the moment the bulb of the incandescent lamp is broken. This eliminates the possibility of obtaining sparks or getting the filament to glow in case the miner should attempt to push the bulb back into its normal position; it also protects the battery from being short-circuited for any length of time, in case the leads to the bulb have become short-circuited during the accident.

As stated before, the upper part of the lamp turns on the lower part, opening and closing the switch. This rotating movement is limited by a soft iron pin $m$, which acts as a magnetic lock. This pin can be withdrawn in the charging room by a strong electromagnet, and when this is done, the upper and lower parts of the housing separate, and the battery can be removed for charging.

The storage battery consists of a single *round* lead cell with concentric electrodes inside of a celluloid vessel $A$ covered with a waterproof lid of the same material. Cylindrical electrodes were given the preference over flat ones, as they are stronger and therefore stand rougher handling. They also warp less, so that in charging, the current density can be increased and the length of time correspondingly decreased. The holes in the terminal sockets contain bushings made of acid-proof metal, into which removable terminals, $p_1$ and $p_2$, are fitted. These terminals are pressed upward by the terminal springs $W_1$ and $W_2$ against the contact segments $K_1$ and $K_2$ of the switch, carrying in this manner the current to the incandescent lamp. Terminals and springs can easily be taken out and cleaned by washing in warm water, a very important point. The use of non-removable springs has been found impractical, as they are very difficult to clean, consequently are liable to corrode and break easily. First-class contact springs, however, are imperative for an uninterrupted light service.

In charging storage batteries gases develop, which must have an opportunity to escape. It is therefore impossible to make the cells airtight. An ordinary opening, on the other hand, would have the disadvantage that the acid would run out, in case a cell were upset, and this would destroy the housing of the lamp. In order to overcome this difficulty, the center of the cell is equipped with a celluloid tubing $B$, which is in communication with the upper part of the cell, where all gases collect, by means of a small side tubing $F$. The gases therefore can pass

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from the cell through the side tubing *F* and finally through center tubing *C* into the open, whereas any particles of acid carried along by the gases, will deposit in cylinder *B*. Even if the cell is turned upside down, no acid which may be in cylinder *B*, or any other acid, can escape. In other words, the lamp will burn in any position, without the acid being able to leak out.

The principal dimensions of this lamp are as follows: The weight of the lamp complete is about 5 lb. ($2\frac{1}{4}$ kg.); its height, not including hanger, is $10\frac{1}{8}$ in. (26 cm.); its largest diameter is $3\frac{3}{4}$ in. (9.5 cm.) The incandescent lamp consumes 0.85 amperes at 2 volts. The battery has a capacity of 16 ampere-hours, and the maximum charging current should not exceed 2 amperes.

To meet various requirements this standard design is not

FIG. 3

FIG. 4

only made in four different sizes, ranging in weight from $1\frac{1}{2}$ to 5 lb. ($\frac{3}{4}$ to $2\frac{1}{4}$ kg.), but it is also made with two storage battery cells connected in series, resulting for the entire line in capacities ranging from four to sixteen hours of life for one discharge and producing light from 0.75 to 3 c.p.

Besides this, a number of other modifications have been developed, so that mines can be completely equipped today with electric safety lamps, wherever a permanent wiring in connection with the lighting plant is impossible. Lamps are made for rescue parties, cages, powder magazines, shaft lighting, shaft inspection, loading places, blasting, cars and locomotives (head and tail lamps), etc. A few of these modifications are shown in the illustrations.

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The standard lamp, being of the "lighthouse" type, distributes its light uniformly over the entire surroundings. The modification shown in Fig. 3, known as the "trip" lamp, has the incandescent lamp mounted on one side combined with a reflector concentrating the light rays in one direction. This design is mostly used for inspection trips and head and tail lamps for cars and locomotives. It is made in the same capacities as the standard lamp.

The "shaft" lamp illustrated in Fig. 4 is arranged with an adjustable arm, on which the incandescent lamp is mounted, so that the light can be sent in any desired direction. It is made for from 8 to 24 c.p. and from 7 to 12 hours of life for one charge.

Fig. 5 represents another type of "shaft" lamp, without

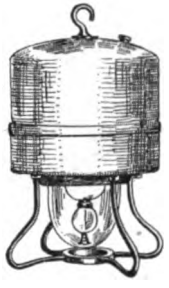

FIG. 5

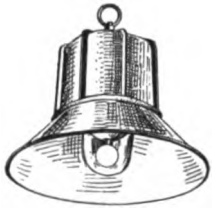

FIG. 6

an adjustable arm. It is made for 8 and 12 c.p. and for 15 and 10 hours of life for one charge.

The lamp illustrated in Fig. 6 is especially suitable for places in which ordinary illumination is not sufficient. It is made for 8 to 32 c.p. and for a life of 7 to 15 hours for one charge.

The lamps so far described were designed to take the place of the Davy safety lamp, which is in use in gaseous mines all over the world. In this country, however, the designer of electric safety lamps is confronted with another problem besides. In a great many mines the crews have and still use "naked" lamps fastened to their caps. On account of the strict enforcement of the mining regulations in recent years, a great many of these mines have been and will be compelled to substitute safety lamps. It is only logical that the men in these mines clamor for a type of electric lamp which is as near identical as possible with the

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present form of naked lamp. To meet this demand, electric cap lamps have been developed, the batteries of which are carried by the miner on his belt and are connected to the lamp by a well-protected special flexible cord. This lamp is shown in Fig. 7.

The principles of construction of the cap lamp (see Fig. 8,) are identical with those of the hand lamp, besides several new features which have been added. One is that the incandescent lamp is mounted inside a parabolic reflector, the opening of which is closed by a lens, instead of being covered with a glass dome; another is a ball joint, permitting the miner to direct the light rays wherever they are needed. The third feature is embodied in the flexible conductors connecting battery and lamp. In case of an accident, there is a possibility that the two conductors may become short-circuited and therefore red hot, event-

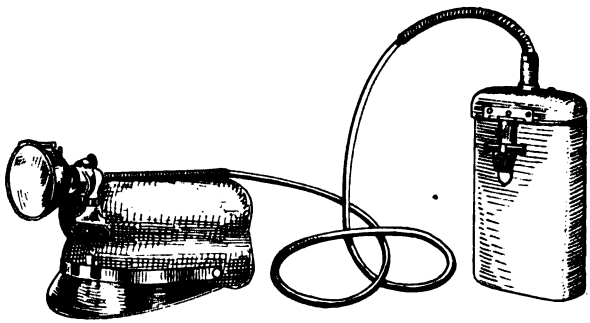

FIG. 7

ually setting the insulation afire, if they are made of copper or similar material. To prevent this a special alloy has been prepared, the melting point of which is considerably below the temperature which is required to ignite insulation or mine gas. Consequently, if a short circuit should take place, the conductors would melt and interrupt the circuit, before there could be a possibility of danger.

From the foregoing description, it can be seen that portable self-contained electric mine lamps of this type have passed the first state of development, and if one considers that more than one hundred thousand are in daily use in Europe, apparently producing excellent results, there is no reason why the adoption of electric mine lamps in this country should not make

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rapid progress in the immediate future. The question whether hand lamps or cap lamps, or both, should be used, is a mere matter of detail, which will adjust itself. European practise has adopted the hand lamp exclusively; the sentiment in this country, however, seems to be in favor of the cap lamp. Men who continually change their location in performing their duties will prefer the cap lamp, leaving both hands free for action; men who stay at work in the same place most of the time will favor the hand lamp, which can be set aside or hung up in the neighborhood, relieving them from carrying unnecessary weight.

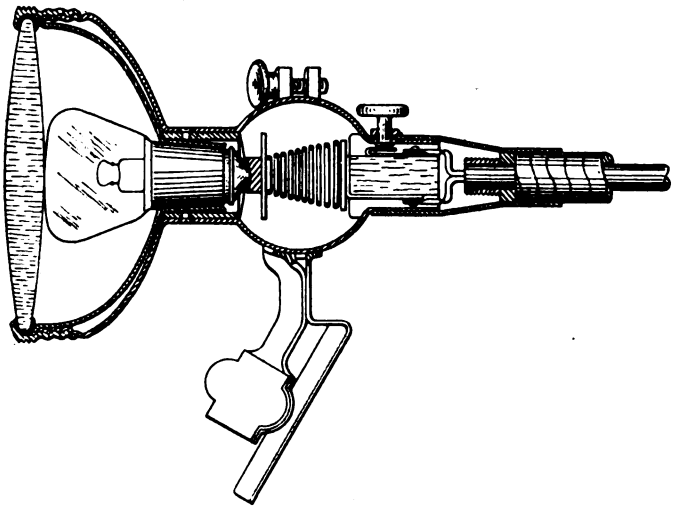

FIG. 8

## LAMP SERVICE

When the crew leaves the mine, the lamps have to be delivered to the lamp room for recharging and cleaning. For this purpose the magnetic lock has to be opened, so that the battery can be removed from the housing and placed on the charging rack. The unlocking is accomplished by pushing the lamp lock against the pole pieces of an electromagnet (shown in Fig. 9), which lifts the soft iron pin holding the upper and lower parts of the housing together.

Special charging racks have been designed to receive the batteries. The rack shown in Fig. 10 is intended for 80 cells con-

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nected in two series of 40 each. Each circuit is equipped with a switch, ammeter and rheostat, so that the operator can determine the status of the charge at any time. The rheostats are provided with a surplus of resistance, so that less than forty cells in a series can be charged, if necessary. A portable voltmeter with a capacity of about three volts is provided to take the voltage readings on the individual cells. Cells are charged, ready for service, when their voltage reaches a value of 2.6. When more than eighty cells are to be charged, two, three or more racks can be combined, and all the cells can be charged at one time.

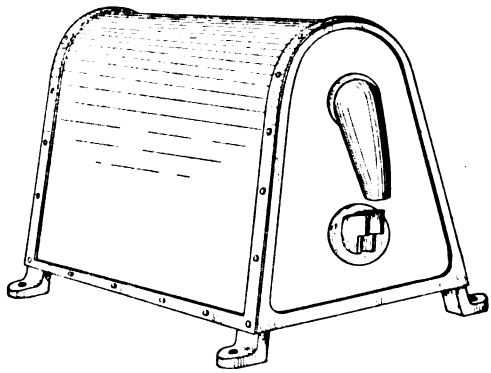

FIG. 9

After the batteries are charged and the contacts and housings have been carefully cleaned, the lamps are reassembled and hung up on special racks, from which the miners remove the lamps, when they begin a new shift.

For mines using a large number of lamps, it is essential that charging, cleaning and repairing be handled systematically and with proper care. For this reason special lamp houses are being erected on the same general principles as those for the Davy safety lamps, but simpler and cheaper, because it is not necessary to make special provision for the safe storage of the fuel, like benzine. The ground plan shown in Fig. 11 represents a lamp house erected for 4000 lamps. It consists of a building about 128 by 33 ft. (39 by 10 m.), containing a charging room with twenty racks, six opening magnets, three small

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motors for buffing and cleaning and a small distribution board with a watt-hour meter. To the left of the charging room is the storeroom for receiving the lamps when they are ready for service, and to the right is a small shop for making repairs. Besides this a small room has been provided for a number of benzine lamps, which are being carried for the fire bosses, and on another floor a washroom for the crew.

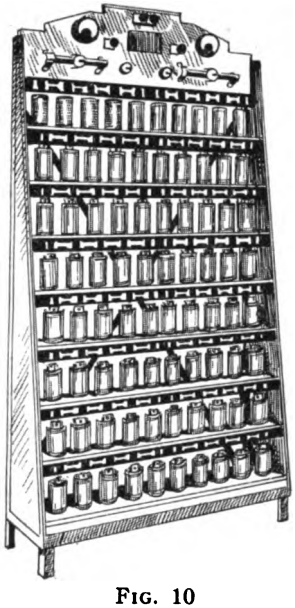

FIG. 10

Proper care of the lamps has considerable effect on the reliability of the service. One of the large German mines, having several thousand electric lamps in daily use, reports that at first about five per cent of all lamps taken into the mine with the beginning of the shift were returned at the end of the same shift, either burning poorly or not at all. By a careful study of all details in the lamp house and by putting a skilled man in charge of the lamp house work, this percentage has been reduced to less than 1.5, with the expectation that it will soon drop below one per cent. That this last-named figure is not an exception, is verified by

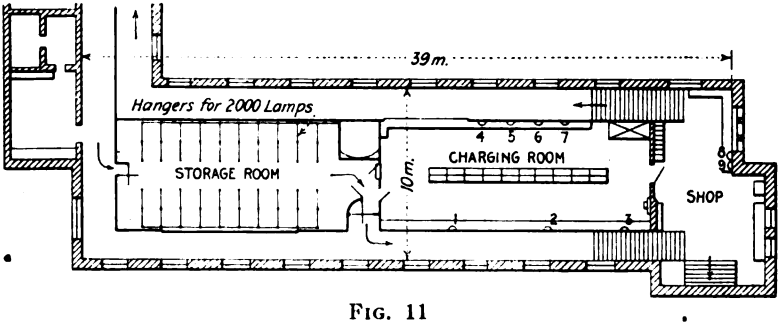


FIG. 11

the Bullcroft Main Colliery Company, Ltd., Doncaster, England. This company has more than 10,000 lamps in daily use and reports the number of defective lamps per shift to be less than one per cent.

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The investigation of these defects, if they amount to 1.5 per cent, shows the following:

| | | |
|---|---|---|
| *Defects caused by the incandescent lamps.* | | |
| Lamps, burning dark | 0.6 per cent | |
| " with broken filaments | 0.2 " " | |
| " " " bulbs | 0.2 " " | |
| Total incandescent lamp defects | | 1.0 per cent |
| *Defects caused by the batteries* | | |
| Batteries, leaking | 0.1 per cent | |
| " discharged ahead of time | 0.3 " " | |
| Total battery defects | | 0.4 " " |
| *Defects due to other causes* | | 0.1 " " |
| Total number of defective lamps | | 1.5 per cent |

Records covering cost of installing and operating electric mine lamps in this country are not available to any extent, because the number of lamps installed is so far not very large and the time during which they have been in operation is comparatively short. However, it should be possible to form some idea of what can be expected, from the experience in Europe.

Although the first cost of electric lamps is undoubtedly higher than that of benzine lamps, the cost of operation, including maintenance, is claimed to average from ten to fifteen per cent less for electric lamps than for benzine lamps. Whether the same results can be obtained in this country, the future will have to decide. It may be added that the cost of the electrical energy is very small and that the cost of maintenance consists about one-third of labor and two-thirds of renewal of parts, and depreciation.

Especially of importance is the cost of renewing the electrodes of the storage batteries, replacement of complete lamps, which are broken on account of rough handling and accidents, and renewing the incandescent lamps.

The life of the electrodes for lead cells ranges from about 100 to 400 shifts, depending entirely upon the treatment which they receive. At the present time large claims are being made for the alkaline cell, which is supposed to last as long as 2000 shifts. This, however, requires verification by actual tests. Besides this, it must be borne in mind that the higher cost of the alkaline cell, the necessity of using two cells, in series, instead of only one as in the lead battery, and the increase in the renewal of the incandescent lamps, due to the large variation in the voltage, will fully wipe out this apparent advantage. However, the weightiest argument against this claim is the fact that the physical life of mining lamps cannot reach 2000 shifts, as shown

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below, and that the natural deterioration of all parts is considerably below this limit.

The replacement of complete lamps which are broken on account of rough handling and accidents undoubtedly varies more or less in accordance with the character of the work performed in the mine. European practise shows that about 0.1 per cent of all lamps per shift are lost in this manner.

The incandescent lamp renewal already has been expressed in figures, in connection with the reliability of service. Excellent results have been obtained, the average life of the lamps being approximately 1000 hours.

From the lamp designs and the lamp service as described above, it can be seen that the development of the portable electric mine lamp has made rapid progress during the last few years, and since, up to this writing, no explosions have occurred wherever installations have been made, it can be said without exaggeration that the electric mine lamp is a success and that it is bound to be adopted more and more.

Of course, as is the case with any new appliance, objections have been raised against the electric mine lamp, especially, because it does not detect in flammable gases as the Davy safety lamp does. There is no doubt that this detail will be overcome in the near future, as there are several principles which can be used for the construction of mine gas detectors. In fact, the German Government only lately has ordered several hundred of these devices, constructed in accordance with the directions of Dr. F. Haber on the acoustic principle and known as "mine gas whistles." These will be distributed to the various mines for a thorough trial.

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DISCUSSION ON "DYNAMO ELECTRIC LIGHTING FOR MOTOR CARS" (WALLER), "ADVANTAGES OF CLUTCH TYPE GENERATOR AND SEPARATE STARTING AND LIGHTING UNITS FOR MOTOR CARS" (CHURCHWARD), AND "ELECTRICAL EQUIPMENT OF GASOLINE AUTOMOBILES" (CONRAD), NEW YORK, N. Y., NOVEMBER 14, 1913. (SEE PROCEEDINGS FOR NOVEMBER, 1913.)

(*Subject to final revision for the Transactions.*)

**H. Ward Leonard:** I should like to put before the meeting what I think are a few of the desirable features we should strive to reach in an automatic lighting system for charging a storage battery and operating the lights upon a motor car, and I think the same conditions, so far as the automatic lighting and charging are concerned, may apply equally well to the case of train lighting. These are very broad generalities that I shall specify and while, in each case, they may have been already realized in some one of the various systems, I am not sure that there is upon the market at the moment any one system that contains them all. The points to which I refer are as follows:

1. The automatic regulator shall so control the dynamo output that under all working conditions, including accidental short circuit, the dynamo current shall not exceed its normal full-load rated current.

2. The automatic control shall be such that current will be forced through the battery even if its resistance be abnormally high due to bad sulphating of the plates caused by neglect, the object being to insure the automatic removal of all sulphate, thereby restoring the battery to good working condition.

3. All movable elements of automatic regulating devices shall act independently of dash pots, liquids, frictional driving devices, pivots, oil, grease, graphite, centrifugal devices, and shall be substantially independent of the effects of gravity, and shocks of the road.

4. The automatic regulator shall not have any part subject to wear and therefore requiring adjustment by the operator.

5. The automatic regulator shall be unaffected by any changes of temperature met with in practise, and the dynamo current shall be independent of the changes of temperature to which its windings are subjected in practise.

6. The racing of the engine shall not materially increase the current produced by the dynamo even momentarily, the object being to avoid subjecting the lamps to excessive voltage with consequent blackening and possible instantaneous burnout.

7. As soon as the battery is so fully charged as to be gassing strongly, the current shall be automatically reduced to prevent the driving off of the water of the battery solution.

8. There shall be provided in plain sight of the operator an automatic indicator, which shall continually and positively indicate whether the battery is fully charged or not, and whether

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the battery is being charged or discharged, and the value of the current into or from the battery.

9. In case the battery be broken or inoperative for any reason, it shall be possible for the lamps to be operated by the dynamo alone, under ordinary operating conditions.

My experience in this line dates back to the time when, in 1888, I put on the first train lighting system in this country, which operated between Chicago and Milwaukee, and I learned at that time, or thought I did, that the chief problem in a case of this character is to maintain the battery in perfect condition, in a condition ready to perform its duty at all times; and this seems to be equivalent to saying that the battery must be kept absolutely free from sulphate and able to deliver its full capacity. I think that is the case in the lighting and storage system in automobiles where there is such a strong demand made upon the battery relative to the area of the plates. It is necessary to keep that battery in perfect condition all the time if we are going to avoid failures in the future. My opinion of the matter is that this boils down to the statement that the whole problem really hangs upon the design of the controller of the dynamo.

**Leonard Kebler:** In reading over the paper by Mr. Churchward, I notice a statement which differs from my previous ideas upon this subject.

Mr. Churchward, speaking of the constant-speed dynamo, says: "Its efficiency, even with great slipping of the clutch, is higher than that of a machine controlled by a bucking series coil, or by regulation of the field current."

This statement is quite contradictory to the theory which I have always held in regard to this matter, and I therefore have had some tests made to check this up.

The theory pertaining to this is that when a motor armature is driven at a constant speed and generates a constant current under any one condition of the battery, with a constant field, then the torque necessary to drive this armature must be constant. The driver of a slipping-clutch-controlled armature varies in speed, but, as stated above, the torque remains constant. The power of the driver is the product of the torque times the speed, so in this case the power will vary directly as the speed.

In practise the clutch begins to slip at a speed of approximately 14 miles (22.5 km.) an hour, and at higher speeds the amperes remain practically constant under any one circuit condition. My theory is that at 42 miles (67.5 km.) per hour the dynamo will require at least three times the power that it does at 14 miles (22.5 km.), although the output remains constant.

The results of my tests indicate that this theory is correct. This additional power necessary at higher speeds is represented by the heat generated by the friction clutch, and by the addi-

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tional power necessary to drive the fan which is used to cool this clutch.

This friction of the slipping clutch necessarily entails a certain amount of wear, consequently a periodic readjustment of the clutch is necessary. Otherwise, the ampere charging rate will become gradually lower until the operator's attention is forcibly called to the low rate by the fact that the battery is not sufficiently charged.

Mr. Waller described a system which employs a shunt-wound dynamo having a vibrating arm in the field circuit, this arm being actuated by the armature current, to rapidly insert and cut out a resistance in series with the field, so as to keep automatically a constant armature current. I know from tests made in the past that such a system takes practically the same power to drive at all speeds above say 14 miles per hour, so I assumed that it was more efficient than the one of which Mr. Churchward says, " Its efficiency, even with great slipping of the clutch, is higher than that of a machine controlled by .....regulation of the field current. "

The tests made were as follows: A variable-speed electric motor, the speed variation being obtained by inserting resistance in series with the field, was run idle at various speeds in order to find the power necessary to run it idle at these speeds. It was then direct-connected to one of the dynamos equipped with a slipping clutch control, and was run at varying speeds with both the dynamo armature circuit and the field circuit open, in order that we might find the increased power necessary to overcome the friction losses, fan loss, etc., of the dynamo. The same tests were then made with one of the shunt-wound dynamos employing vibratory control in the shunt field circuit, described by Mr. Waller. Then separate runs were made with each of these two dynamos, the dynamo in each case being connected to a three-cell storage battery and the controller arranged in each case to deliver approximately 8 amperes. The results of these tests are shown graphically in Fig. 1.

The tests show that at about 2450 rev. per min. the motor driving the dynamo with the slipping clutch required 2¼ times as much power to drive as it did to drive the shunt-wound machine with the vibrating controller. In each case the amperes generated were about 8.

It should be remembered that this includes the loss in the electric driving motor, and if we deduct the amount of power necessary to drive the driving motor idle at 2450 rev. per min. from the amount of power required when the slipping clutch type machine and the shunt-wound machine respectively were being driven by it, we find that the additional power necessary to drive the slipping clutch machine is practically 3.8 times that necessary to drive the shunt-wound machine with the vibrating regulator.

It is common practise to drive the driving member of the

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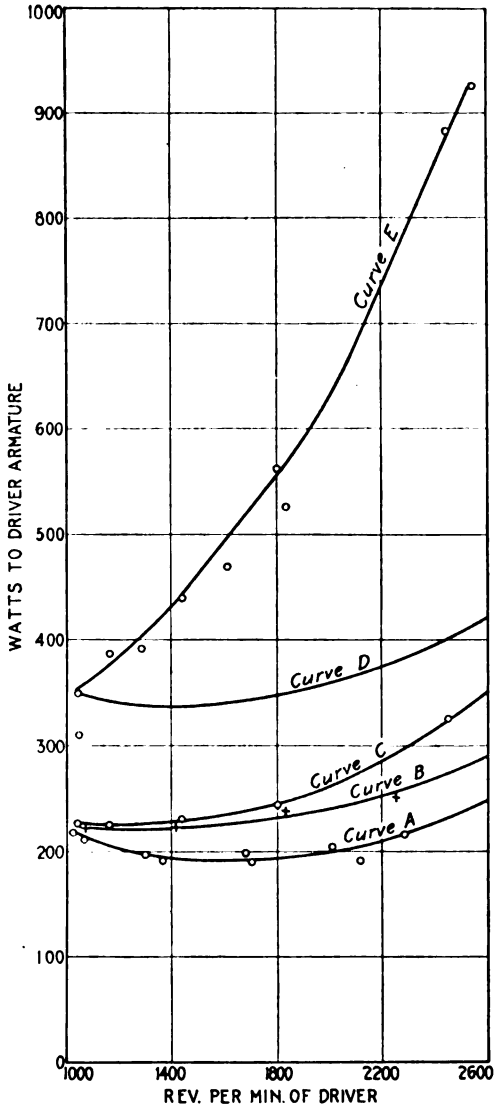


FIG. 1—POWER NECESSARY TO DRIVE DYNAMO WITH SLIPPING CLUTCH CONTROL, AND DYNAMO WITH VIBRATORY FIELD CONTROL, AT VARIOUS SPEEDS.

Curve A—Power taken by driving motor, running idle.
Curve B—Motor driving dynamo with vibratory control, all circuits open.
Curve C—Motor driving dynamo with slipping clutch control, all circuits open
Curve D—Motor driving dynamo with vibratory control, charging three-cell battery at rates varying from 8.2 to 9 amperes.
Curve E—Motor driving dynamo with slipping clutch control, charging three-cell battery at rates varying from 6.5 to 8.5 amperes.

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slipping clutch dynamo in question at 2.7 times engine speed. With this drive a speed of 2450 is the equivalent of about 30 miles (48.2 km.) per hour of the average motor car, geared 3¼ to 1 at the back axle with 36-in. (91-cm.) wheels. When geared in this way the slipping clutch dynamo will give its full output, and the clutch will begin to slip at about 13 or 14 miles (21 or 22.5 km.) an hour. It will be noticed that at 30 miles (48.2 km.) per hour the slipping clutch dynamo takes about 330 per cent more power to drive it than it does at 13 miles (21 km.) per hour. Under the same circumstances the power necessary to drive the shunt-wound dynamo with the vibrating regulator is only 25 per cent greater at the added speed.

**Almon W. Copley:** Mr. Churchward's arguments for the use of a clutch type generator for automobile lighting are in several instances open to question. In his second reason he states that

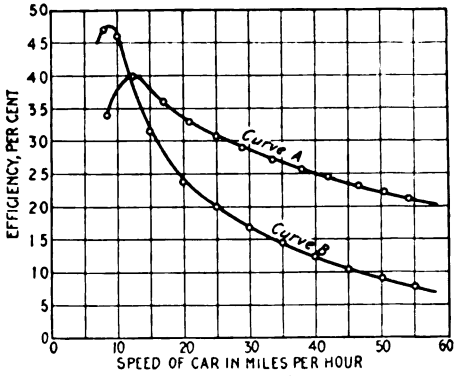


FIG. 2—TEST OF AUTOMOBILE LIGHTING GENERATORS, CHARGING BATTERY ONLY

Curve A—Bucking series coil type
Curve B—Slipping clutch type

the low speed of the armature even at high engine speeds insures long life and reliability. It seems to me that he is overlooking a very important part of the apparatus when he confines himself to the armature. It is true that this type of generator has a low armature speed, but one member of the clutch must revolve at very much greater speed, and moreover, it must be driven at this speed by gearing or chain drive from the engine. Mr. Churchward's curves show that this part must run at about 2½ times engine speed and the problem of driving at this speed is a very serious one. Will not the bearings of this part of the machine wear much more than those of the armature of an engine-speed bucking series coil type generator, or one driven at 1½ times engine speed? The question of the wearing of the chain or gears and the quietness of the drive must also be considered.

But the most objectionable feature of the clutch type machine is

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the clutch itself. It can hardly be supposed that this clutch, slipping as it does practically continuously, can stay in proper adjustment and can have either the long life or the reliability of a machine not using this device. When the engine is running at 1500 rev. per min., *i.e.*, 40 miles (64 km.) per hour car speed, one clutch member is revolving at 3750 rev. per min. and the other at 1200 rev. per min., and with this slipping of 2550 rev. per min. there is transmitted energy to drive the armature and charge the battery at 8 or 10 amperes, it can easily be seen that there will be a great amount of heat generated at the slipping surface and consequent heavy wear and shortened life of the parts.

This also shows the weakness of the fifth argument advanced by Mr. Churchward for the use of this type of machine.

The answer to the third argument, *i.e.*, the comparative efficiency of slipping clutch type and bucking series coil type ma-

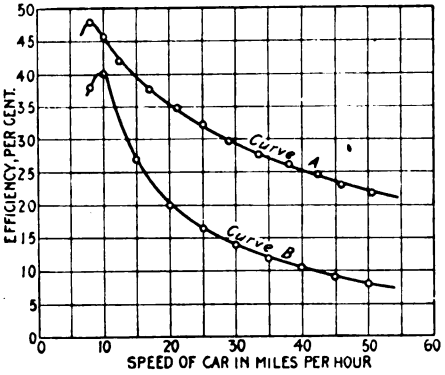


FIG. 3—TEST OF AUTOMOBILE LIGHTING GENERATORS, WITH BATTERY AND 8-AMPERE LAMP LOAD

Curve A—Bucking series coil type
Curve B—Slipping clutch type

chines, is also suggested by what I have said. If there is a large amount of heat generated at the clutch the efficiency of a machine incorporating it must be low. Tests just completed on the latest designs of the best-known make of each of these two types of machine demonstrate this. The curves in Figs. 2 and 3 show the results of the test. Fig. 2 gives the efficiences of the two machines at varying speeds while carrying only the battery charging current (the lamp load disconnected). Fig. 3 gives the efficiency with an 8-ampere lamp load connected. It seems to me that these show clearly the falsity of Mr. Churchward's theory. The efficiency of the "bucking series coil" type is lower than that of the "slipping clutch" type only at very low car speeds with lights off, and at medium and high car speeds, or at all speeds when the lights are on, the former is very much higher than the latter. The dropping off of the efficiency of the

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bucking series coil type at high speed is not such as to indicate extreme core loss under this condition as Mr. Churchward implies.

By reference to the curves the amount of energy absorbed by the clutch can be figured. It is fair to assume that the losses in the armature of the machine are the same at all clutch speeds above 1200 rev. per min., as the armature runs no faster than this. At 1200 rev. per min. the efficiency as shown in Fig. 2 is 40 per cent. The energy supplied the battery is 66 watts. This makes the losses in the armature 99 watts. Now at 50 miles (80.5 km.) per hour (5000 rev. per min.) the energy supplied the battery is the same and the armature loss is the same, totaling 165 watts, while the total energy required to drive the machine is 800 watts. This means that 635 watts are absorbed by the clutch (almost a horse power). The clutch cannot absorb this energy without getting excessively hot and certainly cannot stand this condition without rapid deterioration.

I wish also to point out that the slipping clutch type of machine is not well adapted for the application of ignition parts to it. The best type of machine for this purpose is one driven at engine speed for four-cylinder engines or $1\frac{1}{2}$ times engine speed for six-cylinder. The combination of the two functions in one machine is highly desirable, as it is economical to keep the number of units on the engine a minimum, provided combinations can be made which do not sacrifice anything as regards the performance, life or reliability of any of the individual parts.

Both Mr. Churchward and Mr. Conrad have pointed out the desirability of keeping the starting motor and the generator in separate units, on account of the inherent characteristics of the machines being so different. Mr. Conrad has shown a combined lighting and ignition generator, however, which sacrifices nothing in either the generator or the ignition system. The use of this machine with a starting motor makes necessary only two units; on many of the small engines it is necessary to limit the electrical equipment to this number of units on account of lack of room for more. On the larger engines, also, it is desirable, as it secures the neat, clean appearance of the engine so much sought for by engine and car builders.

I would also take exception to the statement Mr. Waller makes in regard to the merits of the double-wire and single-wire systems of wiring. It should be remembered that almost invariably one side of the battery is grounded—this being done on account of the ignition, which is always of the single-wire system. There is no question as to either the current-carrying capacity or conductivity of the car frame. Therefore, the use of two wires simply introduces an unnecessary complication and a higher resistance return path for the current than the car frame.

With the single-wire system the wire can be better insulated and still take up much less room than the two wires of a double-wire system. The problem of the insulation of the sockets,

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lamps, and other fixtures is much simpler with the single-wire system, as more room is available for this purpose. In any electrical circuit of moderate voltage, whether for railway work, lighting or power work, the single-wire system would invariably be used were it not for the problem of obtaining a good ground return on account of such complications as electrolysis, difference of earth potential, etc. None of these complications is met in the automobile frame and there is no reason at all for complicating an inherently simple system by making it two-wire. Single-wire systems are now used quite extensively for car wiring and have demonstrated their practicability and simplicity.

**A. D. T. Libby:** When the chairman made the statement that the starting and lighting systems were getting down to a point where it was a question of the survival of the fittest, he hit the nail on the head. I believe the whole trend of automobile lighting and starting is fast coming to that point. In the early days, before they had magneto ignition, they started out with four cells of dry battery, giving six volts. Finally some one who had some trouble with his dry cells put on storage batteries equivalent to his dry cells, and they have stuck right along at six volts. The whole trend of engineering, from a power and electric light man's standpoint, is the other way, upward, instead of downward.

There is a mean to all things. If you adopt the 24-volt system, then you must have a controller with a large number of multiple contacts to throw the batteries from series, used in the starting, over to multiple, for the lighting, and the complications involved in this kind of a system are altogether too great for operating in an automobile. I am strongly in favor of, and have always advocated the 12-volt system. It gives the advantages of a higher voltage system without the disadvantages due to complications in the wiring, switches, controllers, etc., and it gives a system which is as simple as the six-volt system, without the many disadvantages thereof. There is no question but that a 12-volt starting motor has more "kick" in it than a six-volt machine. With six volts your brushes are subjected to more or less dust and dirt and you are troubled with these contacts which the low potential will not go through as readily as the 12 volts. I think the final survivor in the starting and lighting work will be the 12-volt system.

The question has been brought up of the single-wire system of lighting cars. There are a number of car makers who are turning out a large number of cars this year with single-contact lamps. I think this kind of a system is wrong. If there is a ground on any one wire of your system, the whole thing is put out of action, while with the 12-volt, two-or three-wire system, or even with the six-volt metallic system, without any ground, if you should happen to get a ground on one wire it will not trouble you at all; in that case you have two chances instead of one. I believe that the single-wire contact systems now being put out will give more or less trouble in the future. They may

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not give any trouble while the car is new, and the wiring is in good order, but when the parts begin to get out of order the trouble will start.

The last speaker raised the point that in the one-wire system, the battery being grounded, trouble was experienced in the ignition system when starting on the battery. The company with which I am connected makes an ignition system that operates with or without a grounded battery, it does not make any difference. We can arrange it in any way desired, and that objection would not have any weight so far as this particular system is concerned.

I agree with the argument of Mr. Churchward, and the other gentlemen, in favor of three units. The starting and lighting are entirely different, and should be kept separate on account of the difference in the characteristics of the machines, and it is very evident to one who has gone over this problem that you can build the two individual machines, and get higher efficiency out of each one, than you can by combining the two into one machine. It has been my experience, too, that the simpler you can make a piece of apparatus, especially a thing you put into an automobile, the better off you are; because when it goes into the hands even of the car builders, it is surprising the things they will do to it. The electric motor-starting system has received a black eye, on account of the complications put in, in all the early systems, and it is now being recognized that these complications must go.

There is one point, on the last page of Mr. Churchward's paper, that is a little misleading. That is where he states that the difference between the weight of the batteries in six-volt and 12-volt systems will be 10 per cent. That is, the increase of weight will be approximately 10 per cent, or as much as the weight of the generator unit itself. Now, if he has a generator that weighs 11 lb. (5 kg.) his statement is correct. Otherwise it is not correct, because you can look in the catalogs of prominent automobile battery manufacturers, and you will find that a 100-ampere-hour battery weighs 59 lb. (26.7 kg.), and a 50-ampere-hour weighs 70 lb. (31.7 kg.), a difference of 11 lb. Any generator suitable to charge such a battery does not weigh less than 20 lb. (9.1 kg.).

Mr. Waller states that the battery should be capable of taking the maximum output of the dynamo indefinitely, and Mr. Churchward states that a dynamo which was giving enough current to take care of the lights, would in time overcharge the battery. I think that Mr. Waller's statement is nearer correct than the other in that respect.

**Harold Goodwin, Jr.:** Taking a previous speaker's objections to the single-wire system as premises, the question may be discussed from the experience of lighting companies. People generally do not test electrical apparatus for grounds until trouble occurs. Therefore, one side of a two-wire system

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might be grounded and the automobile would continue to run practically on the one-wire system with all its objections till the second side became grounded. The installation of indicating test lamps to avoid this, would lead to questions and complications worse than the original trouble. Therefore, it would seem that one well-insulated wire with simple wiring will probably be the victor.

**C. E. Wilson:** I have noted a number of points in the paper by Mr. Churchward, principally in the comparison of the clutch and differential series generators, to which I wish to call attention.

1. The tapering charging current shown in Fig. 1 of the paper is claimed to be due to the fact that the generator is of the clutch type, and the statement is made that the charging current will decrease from ten amperes to about four or five am-

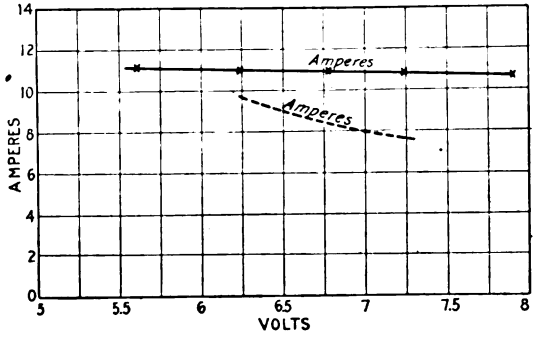


FIG. 4—AMPERES CHARGING CURRENT OF SLIPPING CLUTCH TYPE GENERATOR AT VARIOUS VOLTAGES

Solid line curve, test at constant temperature.
Dotted line curve, replotted from data in Fig. 1 of Churchward paper.

peres when the battery is fully charged, that is, to a voltage of approximately 7.75 volts. A test was made on one of these clutch type generators at variable voltage and the results are shown in Fig. 4 of this discussion. In covering a range from 5.5 to approximately 8 volts the charging current is only reduced about one-half ampere. This test was made with the generator charging a battery, with a booster machine connected in parallel with the battery, thereby making it possible to change the voltage through a wide range. This made a quick test possible and eliminated the effect of heating in the clutch type generator. Comparing the results of this test with Mr. Churchward's curve shown in his Fig. 1, it is evident that the decrease in charging current is due to the heating up of the clutch type generator and is not characteristic of the clutch type generator only. This same effect is noted, possibly to less extent, in the generator of the bucking series coil

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type. In fact, a decrease in the charging current from ten to four or five amperes, as stated by Mr. Churchward, caused principally by the increase of resistance in the shunt field and the armature windings, certainly means an excessively hot machine.

2. In showing a typical regulation curve of a generator with bucking series field Mr. Churchward shows (Fig. 2 of the paper) a very poor regulation indeed. On increasing the charging current from 4 to 7.5 amperes the curve shows an increase in voltage from approximately 6.9 to 7.5 volts. In Fig. 4 of the paper, for the same change in charging current a change in the

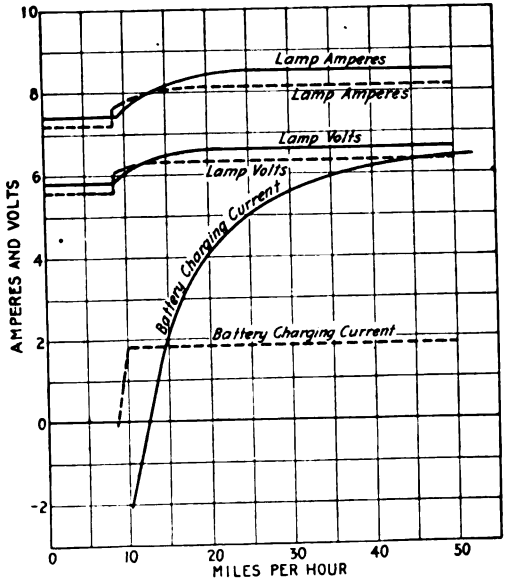


FIG. 5—REGULATION OF AUTOMOBILE LIGHTING GENERATORS
Solid line curves, bucking series field type.
Dotted line curves, slipping clutch type.

voltage from 6 to 6.1 is shown. As this rise in voltage with increase in charging current is due almost entirely to the battery, the increase in voltage should be the same in both cases and not as shown in the two figures. From tests on the two machines which the writer has made personally under the same conditions of battery load, lamp load, etc., the regulations of the two machines are as shown in Fig. 5 of this discussion.

3. In Fig. 3 of Mr. Churchward's paper no data are given as to the speed at which the generator is operating, and the lamp load at the different points. I cannot understand the change in the ampere and voltage curves shown at the end of

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seven hours. Also the increase in current shown from the point at 3½ hours to the point at 5 hours is very questionable unless the test was made under some unusual conditions, which I have been unable to duplicate.

4. In Fig. 4 of the paper a current curve is shown increasing from 4 to 7.5 amperes and holding this value for all higher speeds. The title of Fig. 4 is, "Voltage at lamps at different speeds." I do not understand how there can be a voltage at the lamps unless the lamps are turned on, and from tests which I have made on the most recent of these clutch type generators, the current when the lamps are turned on is not 7.5 but more nearly 4 amperes. Probably this same point was overlooked in Fig. 2 of the paper, where the regulation of the differential series generator is shown. It should be re-

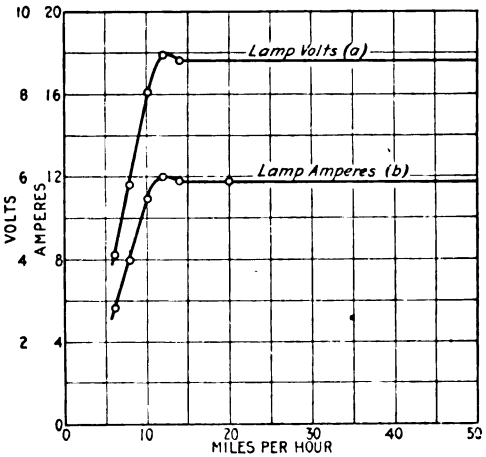


FIG. 6—REGULATION OF SLIPPING CLUTCH TYPE GENERATOR, WITHOUT BATTERY

membered that the voltage obtained at the battery without lamp load fluctuates more widely than when the lamps are connected in circuit, for when the lamps are turned on, the battery charging current at a given speed, and thereby the battery voltage, is reduced.

5. In Fig. 5 of the paper the lamp volts and amperes are shown with the generator disconnected from the storage battery. On making this same test on a clutch type generator of recent design, the regulation was as shown in Fig. 6 herewith. This voltage of approximately 8.75 at all car speeds above 12 miles (19.3 km.) per hour would undoubtedly burn out the lamps in a very short time and make operation on the generator without the battery impracticable. In fact, this point is of very little importance, for in the case of a battery of recent make

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with proper terminals, etc., and a good job of car wiring, it is practically impossible for the circuit from the battery to the generator to become disconnected accidentally.

6. In Fig. 6 of Mr. Churchward's paper the performance of what we might suppose to be a typical starting motor is shown. No mention is made of the voltage at which these curves were obtained. The motor operates on a six-volt storage battery whose voltage, especially if the battery contains only 50 per cent or less of charge, drops very rapidly at high currents. As a matter of comparison, I have shown in Fig. 7 herewith a test on a starting motor, of the type described by Mr. Churchward, on the actual voltage which can be obtained on a car. This motor was of the four-pole circular frame type and weighs about 45 lb. (20.4 kg.). The motor whose curve Mr. Churchward shows differs so widely from this standard

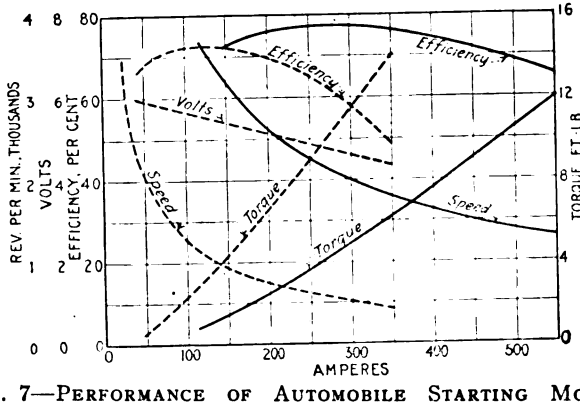


FIG. 7—PERFORMANCE OF AUTOMOBILE STARTING MOTORS

Solid line curves, standard 45-lb. starting motor.
Dotted line curves, performance of motor shown in Fig. 6 of Churchward paper, replotted for comparison.

starting motor that it must be very large and heavy or have some unusual features which should be explained. Another point worth mentioning is the fact that five or six hundred amperes starting current cannot economically be drawn from an 80- or 100-ampere-hour storage battery.

**Benjamin F. Bailey:** When engineers first began work upon the problem of applying electric lighting to the motor car, most of them proceeded upon the principle that the outfit should be a miniature reproduction of a large storage battery station. The writer of this discussion, on the other hand, has always worked upon the assumption that the simpler the apparatus, provided it would operate, the better. This attitude naturally led to the adoption of the differentially compounded generator. It will unquestionably operate. It involves no moving parts in the regulating apparatus, and the chances of trouble are,

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therefore, very remote. There are absolutely no adjustments to be made, as there is nothing to get out of adjustment.

The next problem was to devise a method of connecting and disconnecting the generator from the battery at the proper times. It was desired that this apparatus should be comparable in simplicity with the generator, namely, it must be so simple that it could readily be understood by the average owner or garage man, it must be non-adjustable, and as far as possible, it must be infallible. Particularly, it must never fail to open the circuit when the engine comes to rest.

To secure these advantages the writer was forced to abandon the usual procedure of connecting the generator to the battery when the *voltage* was correct, and instead, make the connection when the *speed* was right. As soon as the connection is made the voltage of a differentially compounded generator automatically adjusts itself, for reasons which it is unnecessary to discuss here.

The means for doing this is the mercury switch shown in Fig. 8, herewith. The construction is nearly self-explanatory. It may be pointed out, however, that the containing shell is without joints, except where the threaded sleeve passes through the shell. The mercury never touches this joint, except possibly at the instant when the switch opens, due to the stopping of the engine. There is, therefore, no trouble from leakage. The contacts are of steel, and even after thousands of breaks show no corrosion. This switch is mounted on the generator shaft inside the housing, and the complete unit, including regulating devices and cut-out, is therefore self-contained.

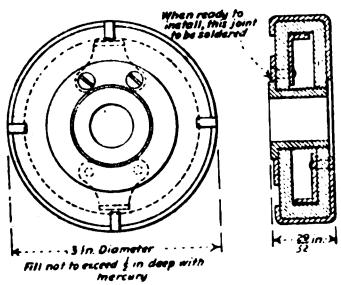


FIG. 8—ASSEMBLY OF MERCURY SWITCH

The writer believes it will be conceded by all that this arrangement leaves little to be desired from the standpoint of simplicity and reliability. It remains to consider what disadvantages, if any, we suffer as compared with the more complicated constant-potential systems. Mr. Churchward mentions five points in favor of his system, in which approximately constant potential is secured by operating the generator at approximately constant speed. A centrifugally operated slipping clutch is inserted between the engine and the generator.

Mr. Churchward's first point is that a constant-potential system charges the battery at a high rate when the battery is low and at a low rate when it is high. The charging rate of a so-called constant-current system is nearly the same irrespective of the charge. Thus there is a small waste of power, and the battery solution loses water faster than would other-

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wise be the case. The first consideration is almost trivial, since the cost of the added power to develop the wasted power is too small to consider. Probably it is necessary to add distilled water more frequently to the battery, but the writer has now operated his car for over two months, during which time he has driven over 1000 miles (1610 km.) without adding a drop of water to the battery. The battery had stood without attention and without the addition of water for about two additional months before installation in the car. This is not recommended as a reasonable way to treat a battery. The writer merely wanted to see what would happen to a battery subjected to unreasonable use.

Mr. Churchward makes the statement that the efficiency of a constant-speed generator with slipping clutch is higher than that of a "bucking field" generator. With the former machine, if the constant speed is say 800 rev. per min. it is entirely possible that the driving member of the clutch is revolving at 3200 rev. per min. The torque on the two members of the clutch is the same and the clutch efficiency is 25 per cent. The combination efficiency would be not over 60 per cent of this, or 15 per cent. Actual tests of the system I am describing shows an efficiency of not less than 50 per cent at the above speed, and a somewhat higher efficiency at lower speeds. It must be remembered that the core loss does not increase in proportion to the speed, since the flux is weaker at the higher speeds.

The point is also made that it is possible to operate a constant-potential system with the battery accidentally disconnected. Undoubtedly this is so, but it should be pointed out that the same is true to a certain extent of a properly designed constant-current system. The writer finds that for speeds between 15 and 30 miles (24 and 48.2 km.) per hour, the lighting is satisfactory, and no difficulty would be experienced in getting home with the light generated in this way.

The company with which the writer is associated builds only six-volt systems. We believe that a somewhat more efficient motor may be built for 12 volts, since the commutator loss will be less, but are inclined to think that the greater weight of the 12-volt battery more than makes up for this.

The question whether it is better to have the generator and the cranking motor separate units or to combine the two is still an open one. The writer has designed and built both types. There is little difference in weight. The single-unit system is more convenient from the standpoint of the operator, since, as usually applied, no shifting of gears is necessary, this being accomplished automatically by the mechanism. This is not, however, an invariable rule.

With the two-unit system, it is believed that it is preferable to design the motor powerful enough so that only a single reduction gearing need be used. This is usually accomplished by the

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use of a pinion on the motor shaft and a gear bolted to the flywheel or cut in the face of the flywheel itself. This requires a larger and more powerful motor, but the much higher efficiency (due to the lower gear loss) and the saving in the weight and cost of the gearing, will more than offset this. The total gear reduction would be about ten to one.

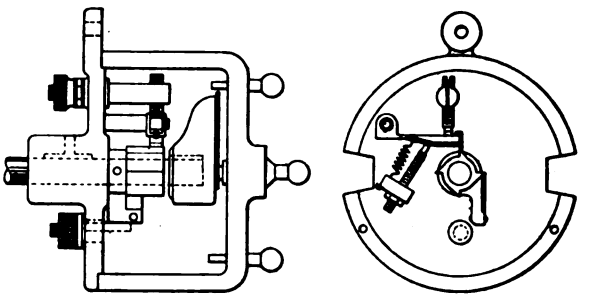

FIG. 9—ASSEMBLY OF TIMER AND DISTRIBUTOR

I am a strong believer in the use of the same system which supplies power for lighting and starting, for ignition also. Since it dispenses with a number of the parts of the magneto it can be made more reliable than the latter. Two strong points in its favor are that it can supply a strong spark even at zero speed, and the fact that the spark advance on a properly de-

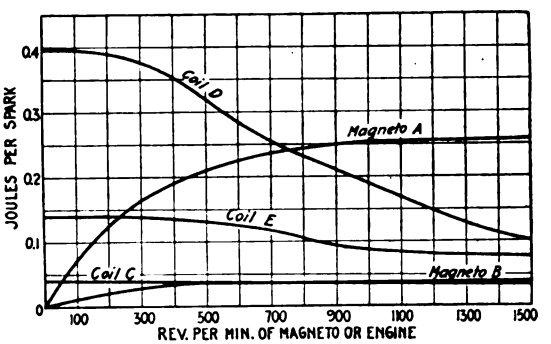


FIG. 10—COMPARATIVE OUTPUTS OF VARIOUS IGNITION SYSTEMS

signed system is absolutely unlimited. This is a point against the magneto which is often not given the attention which it deserves.

In Fig. 9, herewith, is shown the mechanism of the ignition device used in the system I am describing. This arrangement gives a quick break, the speed of the break being absolutely independent of the speed of the engine. Provision is made for

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the possibility of a momentary backward rotation of the engine by the use of a double ratchet arrangement applied to the cam.

The arc of contact is constant, and therefore the time of contact is greater for low speed. To avoid too great a difference in the strength of spark at low and at high speeds a " quick " coil is used so that time is afforded for it to become practically saturated even at high speeds.

A great number of tests have been carried out upon different ignition systems, to determine the output in joules per spark. This, as pointed out by Mr. Conrad, is not entirely a fair comparison, since not only the total energy per spark, but also the rapidity with which it is liberated, is of importance. In other words, what happens after the gas has been ignited is of no importance. Our knowledge regarding some of these points is rather limited, and perhaps the total energy per spark is as good a measure as any. The curves shown in Fig. 10, herewith, give the results of some of these tests. Coils *D* and *E* are of the writer's design. Magnetos *A* and *B* are both well-known makes. Coil *C* is that of a well-known constant spark system. All of these outfits gave good results in service, and all except coil *C* have been personally tested by the writer upon actual cars. Coil *D* is the one the writer uses for general purposes. As a matter of fact, coil *E* seems to give as good results, except possibly in starting a very cold motor. Magneto *A* is a very large one weighing over 30 lb. (13.6 kg.), and is intended for low-speed work. The magneto outputs are those obtained at the best point of spark advance. In actual service, at high speed and large angle of advance, the output would be much less.

**Kingston Forbes:** Let us look at the question of starting and lighting an automobile from the automobile engineer's standpoint. When the automobile manufacturer has decided to install electric lighting and starting apparatus on his cars, he turns to the trade papers, and finds there are some 42 different outfits being marketed by electrical manufacturers throughout the country for this purpose. Not being an experienced electrical engineer, he has to depend on the recommendation of the salesman-engineers, and he is confronted with the problem of whether to use a 6-volt, 12-volt, or 24-volt starting and lighting circuit. The essential requirement in an automobile is to get it as simple as possible. The multiplicity of control in the present automobile is greater than a great many of the operators and laymen care to handle. This makes the simplicity of the electrical apparatus an important consideration. The use of the 12-volt or 24-volt system necessitates complicated wiring and switching, and the automobile manufacturer does not like to confront his customers with this proposition.

Studying this situation carefully, it seems to me that the single-wire system affords the greatest simplicity in respect to the lighting system of the car. In looking over the chassis of a car, if there

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is a multiplicity of wires incident to the lighting and starting system it frightens the admirer of the automobile. With the use of the single-wire system, it is possible for the chassis and body to be so wired that by three disconnections the body can be disconnected from the chassis, and the chassis can be so wired that all visible evidence of the wires is practically eliminated.

Another problem connected with electrical apparatus is where to put the various units. There are two or three alternatives offered to automobile engineers—the single-unit system, the double-unit system, and the three-unit system. It seems that it is not advisable to complicate matters to the extent of having one piece of electrical apparatus to supply the demands of ignition, lighting and starting. It seems to me that the electric starting motor in its simplest form, series-wound, would take care of starting, and, going a little further, it would seem that a generator, with a combined apparatus to take care of ignition, should be the logical consequence. This cuts down the electrical equipment to two pieces of apparatus, which, to go a little further, can be coupled up directly to the water pump shaft. By installing the generator like an ignition outfit, connected to the pump shaft, we get a direct-coupled system which is very easy to install when the chassis is being assembled.

As regards the installation of the starting motor, different problems are presented to us, inasmuch as the position of various other parts of the engine is fixed in accordance with the designer's ideas. This makes it necessary for the starting motor to be placed in such a way that it will not interfere with other parts of the chassis.

Still another problem which confronts the automobile engineer is the mode of operating the starting motor—whether by means of a simple switch or a complicated set of levers and overrunning clutch and gear reduction sets. We look to the electrical engineer to simplify the application of starting motors, and the automobile engineers must coöperate.

Up to the present time considerable trouble has been experienced with starting switches to handle comparatively low voltages and high amperages.

**Alexander Churchward:** I have been trying for four years to get a discussion openly on the slipping clutch machine. All I could get was the statement, " We do not use slipping clutches ". But the fact remains that between thirty and forty of the leading automobile manufacturers throughout the United States and Europe are being supplied with the slipping clutch machines and these companies find by actual test that they cannot get similar good results with any other appliance. They would like to be able to dispense with these slipping clutches if they could, but they cannot.

As to criticising the slipping clutches in regard to mechanical adjustment, all I can say is that they do not need as much and as frequent adjustment as the vibrating regulator machines now

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in the market. I have seen them tested against the slipping clutch machines which they claim wear so badly, when the latter stood up ten times as long without adjustment as the vibrating regulator machines. That is why so many companies use the slipping clutch machines.

**Alfred E. Waller:** One of the most deceptive problems the automobile engineer has to face is the old question of the single-wire system with ground return. I believe that most people who recommend the single-wire system are not familiar with its application in automobile work. It is obvious that the metal car frame is capable of carrying current far in excess of the amount required by automobile lamps. The point is that it is not an easy matter to get the current from the lamp terminals to the car frame and from the frame to the battery, due to the difficulty of obtaining good ground connections which will not corrode.

In motor car headlights, as they are made at the present time, the socket that holds the lamp is brazed or otherwise securely fastened into a parabolic reflector of spun metal. The reflector is held in the headlight by an expanding ring which fits in the front cover of the lamp or by some other equivalent means. There is no doubt that the current may be carried satisfactorily on any kind of a continuous metal path, but this method gives a conductor full of joints which may or may not make good contact. You have to start with a socket and get from the shell of the socket to the reflector, and from the reflector to the lamp frame through the expanding ring. Then the circuit runs through the hinge and frame of the lamp to the lamp bracket, then to the car frame. The alternative is a ground wire from the socket to the car frame, and such a wire must not be merely clamped against the frame because it will rust and corrode and consequently make poor contact. You have to drill the car frame and tap it and secure the ground wire by means of a screw set up tight so that you get a continuous metal path which cannot, under any conditions, be affected by corrosion.

It was stated in the discussion that the wiring could be simplified by using a single-wire system. Does it make any difference whether you run two wires in the same sheath or a single wire? The cost of the extra copper for the two-wire system is insignificant. As far as large users of power are concerned, it should be remembered that all of the street cars of New York City are using the metal return. No buildings are wired with a ground return. Very few boats, and none of recent construction use ground return. The United States Navy has absolutely specified against it after trials which showed it to be unreliable and costly.

Finally, if armored cable is used with the sheath forming the ground return, you have practically the two-wire system with one conductor entirely uninsulated, so that the system is operating at 50 per cent efficiency under the best conditions. I do not understand how any automobile engineer familiar with the difficulty in carrying current through ground connections can be deceived in the matter.

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**Frank Conrad:** The only objection made to the bucking series type of generator was that it does not give the tapering charge described as being desirable for charging the battery. In Mr. Churchward's paper the first advantage given to the clutch type generator is that it charges a battery as it should be charged; that is, with a comparatively large current when the battery is low and empty, tapering off to a small charging rate when the battery is full and at the gasing point.

Fig. 1 in Mr. Churchward's paper gives for the initial charge 9.6, and for the finish about 7.75 amperes, and the battery which will be required for a car installation with a starting motor would stand a continuous rate of 10 amperes, as pointed out by Mr. Waller. It is therefore evident that the initial charging rate obtained by the clutch type generator is no real advantage. Any tapering of the charge is probably due to heating rather than to increase of voltage. Comparative tests have been made of a bucking series generator and a clutch type generator, operated with a resistance load instead of a battery, so that the voltage was constant. The results showed that the actual taper of the bucking series generator is of a greater percentage than the clutch type. That effect is due to the heating of the shunt coil.

In his comparison with the high-voltage batteries, I believe (and the point has been brought up before by another speaker) Mr. Churchward takes a 6-volt battery and divides the plates in two. Of course, if the battery maker were making this battery he could use a different plate to make the capacity even, and then the weight would not be so great.

If the actual increase of weight was 10 per cent, with the average generator with which I am familiar, that would mean a battery weighing 200 lb. (91 kg.), probably 250 lb. (113 kg.).

**Alden L. McMurtry** (by letter): Mr. Waller's statement that " in practically all instances the system of running two wires to each lamp and fixture has been adopted, " may be criticised. Automobile engineers are adopting the one-wire system on account of simplicity, stability, and freedom from electrical troubles.

The automobile wiring problem is entirely different from that pertaining to the street car, steamship or railroad coach. The longest circuit is less than 100 in. (254 cm.), and the troubles encountered are all mechanical rather than electrical. The drop in voltage is less than in the average two-wire system, and the supposedly " poor connections " in the lamp are theoretical.

I have made numerous tests on this subject, and my reasons for advocating the one-wire or grounded system are as follows:

(a) It is stronger mechanically, especially in regard to receptacles; simpler for average operator to locate wire troubles.

(b) It will stand a higher insulation test.

(c) The average electrically-lighted automobile has one side of the battery grounded to the ignition system, and has there-

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fore actually a one-wire system, although subject to all the troubles of the two-wire system.

(d) The connections are larger, insuring better contacts at the lamp base.

(e) The amount of current is too small to cause electrical troubles, at connections to the frame of the car.

Inspection of automobiles that have the one-wire system will disprove all arguments used against it.

A point in the discussion of high-voltage systems which is of great importance is the size and form of the tungsten filaments. The six-volt lamp has a small concentrated filament, which makes it easy to focus the lamps. Higher voltage means a longer filament of smaller size, and therefore it will be a difficult matter to focus a searchlight properly. In England, where the 12-volt system is almost universal, the various automobile lamp makers have various forms of reflectors which require a special type of incandescent lamp. This not only lessens the effectiveness of the lamps, but restricts users to lamp renewals supplied only by one manufacturer. The candle power of the tungsten lamp is a secondary consideration to the form of the filament. The distance to which useful light is projected ahead of the automobile is governed by the intensity of the lamp. Lamps of higher candle power cause a greater drop in voltage, and therefore the intensity of the light, and the distance it is projected, is less, while the large area of the filament gives a beam of light of a slightly greater angle.

Some of the arguments against the clutch type of generator are not based on fact. I have personally tested this type of generator over a period of more than 600 hours' continuous running. The wear on the clutch surfaces was not perceptible, owing to the fact that the surface requires very little pressure. I have on my car a clutch type generator, which has been in constant use since December, 1910, and the only attention required was for lubrication, which was needed about once every six months. The rate of current output has decreased approximately seven per cent during this period.

**Frederick S. Dellenbaugh, Jr.** (by letter): In the early development of any new apparatus correct operation and reliability are of prime importance and the criteria of success. But as the art develops refinements in all directions are introduced and one of the main aims is improvement in efficiency.

This is clearly to be seen in the present case with electric lighting generators for automobiles, and more attention is being given to decreasing the power losses. The gas engines themselves are cut down in every detail to add a little to the efficiency and therefore the choice of a lighting generator, other things being equal, should be governed by the requisite input.

Though of course the most dependable comparisons are based on actual tests, provided they are accurate and made under conditions actually duplicating the ordinary service, it is in-

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teresting to investigate the theoretical considerations of the case, as they show what should be expected and, if all factors are included, give approximately correct results.

Except for variations in individual design, the most widely differing types of lighting generators are the constant-speed and the variable-speed types. All the machines built can be included under these heads. In any generator the losses are:

Copper losses due to resistance of windings.

Core losses due to hysteresis and eddy currents in armature core.

Windage losses and friction losses.

Minor losses under load which are practically negligible.

In addition to these we have transmission loss in applying power to the generator.

Taking up first the variable-speed generator, the losses in windings are practically constant as the current in most types is constant.

The windage and friction losses increase with the speed. The windage is very small so that we should expect these losses to be nearly proportional to the speed. In this type of generator the transmission loss can be considered as part of the friction loss.

The variation of the core loss is more complex. Compared to the wide range of speed the voltage can be considered approximately constant.

If $\phi$ = field flux,
$n$ = speed,
$v$ = volts,
$B$ = flux density,

then volts $= K_1 n \phi$

$K$ being proportionality factor.

Or $$\phi = \frac{K_1 V}{n}$$

Core loss $= K_2 n \times B^{1.6}$ approximately, as the eddy current loss is a very small percentage of total.

$B = K_3 \phi$ in any one machine, dimensions being constant. Substituting,

$$\text{core loss} = K_4 n \times \phi^{1.6} = \frac{K_5 n \times V^{1.6}}{n^{1.6}} = \frac{K_5 V^{1.6}}{n^{.6}}$$

Thus, if voltage is assumed constant, core loss will decrease slightly as speed increases. Taking the sum of the losses:

Total loss = Core loss + copper loss + windage friction

$$= \frac{K_6}{n^{0.6}} + K_7 + K_8 n$$

If we assume $K$ to make losses equal we have:

$$\text{Total loss} = \left(\frac{35}{n^{0.6}} + 1 + 10^{-3} n\right) K_9$$

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If $n$ = 1000 rev. per min., total loss = 3 $K_g$.

If $n$ is increased to 3000 rev. per min., total loss = 4.56 $K_g$ or an increase of 52 per cent.

Thus, if efficiency were 50 per cent to start with, at 3000 rev. per min. it would now be 39 per cent, or the input would be increased 11 per cent. This is actually a little low, but serves for the purpose of illustration.

In the case of the constant-speed machine, on the other hand, all the losses in the generator itself remain constant and the transmission losses vary. The only successful constant-speed generator that we know of is the one described by Mr. Churchward in his paper, and this uses a clutch which slips above a certain speed. It is evident that for any stable operating condition the torque at the two adjacent faces of the clutch must be the same. The power developed or required is proportional to the torque times the speed, and therefore as the speed of the engine increases the power supplied to the clutch increases in direct ratio, while the power required to run the generator remains the same.

Evidently, then, if the speed of the engine increases to three times that at which the clutch just begins to slip, the efficiency of transmission must be reduced to 33 per cent, provided it be considered 100 per cent with no slip.

Comparing this with the figures for the variable-speed generator, if we assume slippage to begin at 1000 rev. per min., and efficiency over all at this point 50 per cent as before, and losses = 3$K_g$, then the input = 6 $K_g$. At 3000 rev. per min., the input to the generator will still be 6 $K_g$, but, as shown above, the power on the high-speed side of the clutch must be three times this, as the torque is the same, and so the input there is 18 $K_g$. Out of 18 units only 3 are being used, as the efficiency over all is now 18.7 per cent.

From this it is evident that the constant-speed machine, whatever its advantages may be in other ways, is inherently extremely inefficient unless some device which will transmit power by transforming torque as well as speed be used, and the variable-speed machine has actually a fairly uniform range of efficiency over its complete range of speed.

**John R. King** (by letter): Referring to that portion of Mr. Waller's paper wherein he speaks of the necessity of regulating the control of the output of the lighting generator under varying speed conditions, and gives several methods of obtaining regulation, I would like to call attention to a type of generator developed in Germany during the years 1904 and 1905, by Dr. Emmanuel Rosenburg, and used in connection with a storage battery, for lighting railway trains. This apparatus is described in the *Electrical World and Engineer*, Vol. 45, p. 898; Vol. 46, p. 104, and the *Electrical World*, Vol. 48, page 918.

As automobile lighting requirements are similar to those of railway trains, it would seem that unless conditions of design for the smaller units interfere, this type of generator and lighting

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system could be applied with success to motor cars. Briefly, the design and operation of this type of generator are as follows: the armature is the same as that in an ordinary direct-current machine, but the field construction is somewhat different, the field poles and frame having a small cross-section and the pole shoes or faces being considerably larger, spanning nearly the entire armature surface, and being notched and cut away at the middle point along the line of the armature conductors. There are double sets of brushes, one set being placed on the ordinary electrical neutral and the other set displaced 90 electrical degrees therefrom. The brushes set on the neutral are short-circuited and current is collected from the displaced set. The simplest type of machine is one that is shunt-wound.

When the machine is started the voltage increases in proportion to the speed until the point of magnetic saturation of the smaller cross-section of the pole pieces and frame is reached. For any further increase in speed, the flux in the field frame is but slightly increased, and the cross-flux created by the coils under the short-circuited brushes tends to counteract this increase, and to hold the current output constant, due to the large stray field in the enlarged pole shoes. The result is that the machine will deliver a constant current with varying voltage conditions over a wide range of speed, or if the outside resistance is constant the machine will deliver approximately constant voltage independent of speed. Other conditions and refinements may be obtained by introducing a series field winding.

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*Presented at the 295th meeting of the American Institute of Electrical Engineers, New York, May 19, 1914, under the auspices of the Committee on Use of Electricity in Marine Work.*

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# THE FUTURE OF ELECTRIC HEATING AND COOKING IN MARINE SERVICE

BY H. J. MAUGER

ABSTRACT OF PAPER

Indications of the future point to electric motor driven propulsion and abandonment of coal-burning boilers. Electric cooking and heating is in line with this development and the source of heat for cooking and heating will be confined to the boiler room. The future of electric cooking apparatus is assured by the progress already made in the U. S. Navy in adopting electric equipment. Detail report is given of trial trip of U. S. *Texas*, which depends almost entirely upon electricity for cooking. Consumption of 1.25 kw-hr. per person per meal is indicated. Load factor was 50 per cent.

Electric ranges and bake ovens effect considerable saving in weight and space and release cooks from being "firemen" to devote their time and effort to good cooking. Electric cooking finds greatest advantages in high temperature cooking.

Electric heating on shipboard does away with the disadvantages of steam piping and gives individual and local regulation and provides, where desired, glowing heat without fire.

Other accessories are the electric flatiron, the soldering iron and therapeutic devices.

IF we may be permitted to look into the future five or ten years, we venture to make the forecast that first-class vessels will be driven by electric motors, direct-connected to the shaft of the propellers, the electricity being generated either by steam turbine-driven generators, energized by steam furnished from oil burning boilers, or else by electric oil-generator sets.

In assuming the role of a prophet, we naturally enjoy the freedom of a wide latitude and place ourselves beyond the sphere of criticism, but we believe that the members of this Institute will agree with us, at least, that signs point in that direction.

On board ship, very important, if not paramount, are the considerations of saving in space and weight, as well as considerations of cleanliness and convenience and despatch; and nothing that we know of at the present time so completely and satisfactorily meets these requirements for their purpose as the electric range and bake oven—with their culinary accompaniments—on the one hand, and the electric air heater on the other, not to



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speak of such miscellaneous applications as the flatiron, the soldering iron etc. In other words, in our vision of the model ship of the future, we can see no other source of heat and power than electricity, outside of the boiler or engine room.

When we realize that a number of the U. S. battleships, not to speak of submarines and army transports, recently constructed or in process of construction, have adopted electric cooking and heating in full or in part after the most thorough investigations, extending over a period of years, electric heating and cooking in marine service becomes an established fact, and it remains only to see what the future may bring forth.

Among battleships which have been partly equipped with electric cooking and heating are the *Arkansas* and *Wyoming*. The battleships, *Texas*, *New York*, *Nevada* and *Oklahoma*, which are now under construction, have the galleys and bakeshops completely equipped. Already thirteen submarines have been equipped entirely, and eight more are in process of construction.

The *Wyoming* has three electric ranges in the officers' galley and electric cooking is there used exclusively; in the crew's galley, there are four electric ranges and four coal ranges. The *Wyoming* was equipped with the latest design of ranges December 24th, 1912, and has had no appreciable trouble, except with the hot plates of the cooking surface, which has since been overcome.

Recently the army transport *Thomas* returned from Manila carrying about 1500 troops and crew. Two type *D*-47 bake ovens, capacity 108 one pound loaves, proved sufficient to bake all the bread, pastry, etc. required, although three ovens were available. No trouble was experienced, and everyone interested was pleased with their operation.

Of special interest, is the recent trial trip of the battleship *Texas*, made during last October, because for the first time a large number of men (715) at sea were entirely dependent upon electric cooking for their daily meals. During the run of two weeks, there were no break downs of any kind and the cooking was done in a perfectly satisfactory manner.

The results of this trial demonstrated that the equipment was more than sufficient to take care of the ship's full complement, which will comprise about 1070 men, including 70 officers. This ship's equipment consists of 15 electric ranges, type D-48, and 2 bake ovens, type D-50, and with the exception of some

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supplementary steam kettles and coffee urns in the crew's galley, there is no other means of cooking or baking available on this ship. The success of the trial is all the more apparent in view of the fact that none of the cooks had any previous experience in using electric apparatus and that they so readily became acquainted with its operation and had no difficulties in performing the duty required. The attendants, without exception, were pleased with the performance of the electric ranges, as well as the bake ovens, being much impressed with their greater efficiency and cleanliness.

The trial trip of the *Texas* is also significant because for the first time has it been possible to obtain such complete and valuable data.

Five ranges are installed in the officer's galley, four of which were in daily use; and in the crew's galley there are ten ranges, six to eight of which were used daily during the trial, as well as two bake ovens in the bakery. The officers' galley served 162 men and the crew's galley 553 men; a total of 715 men. The ovens proved to be of sufficient capacity to supply a crew twice as large as that aboard, and they were perfectly suitable for all kinds of work demanded of them. The officers' galley was in use from 6 a.m. to 9:30 p.m. (except an hour and a half from 2:30 p.m. to 4 p.m.). A few hot plates were kept in service at all times, supplying hot coffee. The crew's galley generally was in use from 4:30 a.m. to 8:30 a.m.; 10 a.m. to 1:30 p.m.; and 4 p.m. to 8:30 p.m., depending somewhat on the daily menus.

Referring to Fig. 1, the top curve shows the daily cooking load, in kilowatt-hours, which average 1258.6, the highest daily load being 1695 and the lowest 806 kw-hr. The downward slope of the curve shows a radical increase in economy as the cooks became accustomed to the use of the electric ranges, and the economy would be still further increased by longer experience. This consumption proved to be an average of 1.7 kw-hr. per person per day for the total; but further reference to the accompanying curve shows that the average total consumption of the crew's galley (556 kw-hr.) was only slightly more than that of the officers' (519 kw-hr.). The average consumption per man per day of the crew's galley was one kw-hr. as compared with 3.2 kw-hr. of the officers. The average daily consumption of the bakery was 182 kw-hr. total, or 0.25 kw-hr. per man. Without doubt, the total consumption for cooking and baking should not average more than 1.25 kw-hr. per day per person, instead of 1.7 kw-hr.

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In accounting for the difference of the energy consumption per man in the officers' galley as compared with the crew's galley, we have to consider that there is no steam cooking in the former and this would account for 25 or 30 per cent of the total consumption. It should be further noted that the officers galley was operated somewhat on the plan of an *a la carte* or

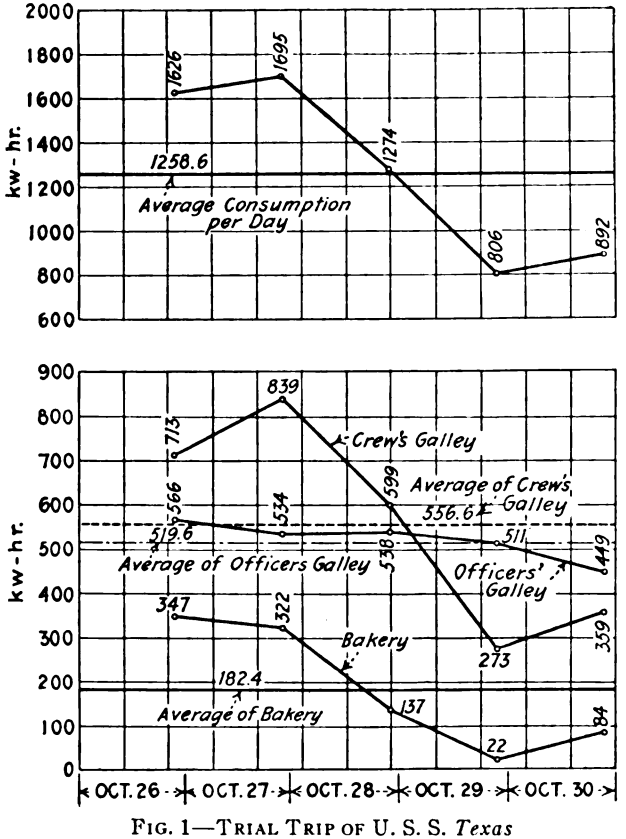


FIG. 1—TRIAL TRIP OF U. S. S. *Texas*

Total current consumption of electric ranges in bake ovens Oct. 26 to Oct. 30, 1913, inclusive. Officers galley served 102 men; crew's galley 553 men; bakery served 715 men.

European plan restaurant where the meals were strung out over longer periods—more severe service than will actually be obtained when in commission; while in the crew's galley, advantage accrued from cooking for a much larger number of men at one time. Reference to the menus shown in the curves will indicate that the crew fared very well.

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Fig. 2 shows the load curve for the ranges in the officers' galley on Oct. 30th, in which the total consumption was 451.7 kw-hr. The average kilowatt demand was 27.4 while the maximum (during the dinner period) reached 54 kw-hr. Four

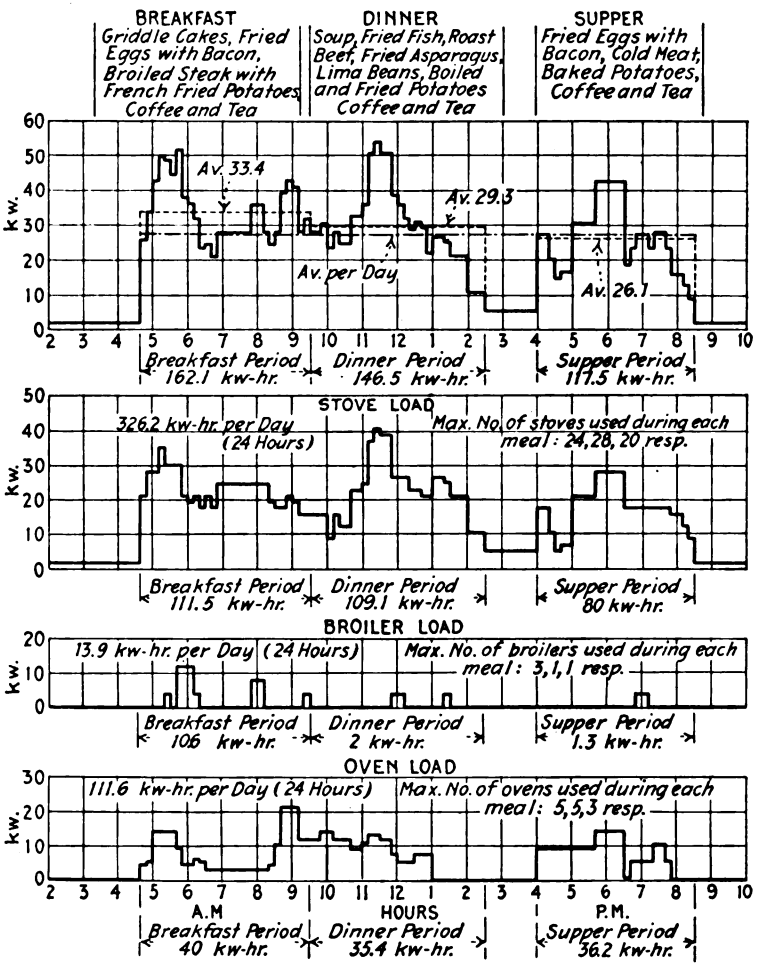
BREAKFAST
Griddle Cakes, Fried Eggs with Bacon, Broiled Steak with French Fried Potatoes Coffee and Tea
DINNER
Soup, Fried Fish, Roast Beef, Fried Asparagus, Lima Beans, Boiled and Fried Potatoes Coffee and Tea
SUPPER
Fried Eggs with Bacon, Cold Meat, Baked Potatoes, Coffee and Tea
kw.
Av. 33.4
Av. 29.3
Av. per Day
Av. 26.1
Breakfast Period 162.1 kw-hr.
Dinner Period 146.5 kw-hr.
Supper Period 111.5 kw-hr.
STOVE LOAD
326.2 kw-hr. per Day (24 Hours)
Max. No. of stoves used during each meal: 24, 28, 20 resp.
Breakfast Period 111.5 kw-hr.
Dinner Period 109.1 kw-hr.
Supper Period 80 kw-hr.
BROILER LOAD
13.9 kw-hr. per Day (24 Hours)
Max. No. of broilers used during each meal: 3, 1, 1 resp.
Breakfast Period 106 kw-hr.
Dinner Period 2 kw-hr.
Supper Period 1.3 kw-hr.
OVEN LOAD
111.6 kw-hr. per Day (24 Hours)
Max. No. of ovens used during each meal: 5, 5, 3 resp.
A.M
HOURS
P.M.
Breakfast Period 40 kw-hr.
Dinner Period 35.4 kw-hr.
Supper Period 36.2 kw-hr.

FIG. 2—TRIAL TRIP OF U. S. S. *Texas*

Five ranges, 162 men—energy consumption of electric ranges in officer's galley October 30, 1913, (24 hr.) 451.7 kw-hr.—coffee and tea are kept hot at all hours.

ranges were in actual use in the preparation of this meal. The load factor, taking it as the ratio of the average to the maximum demand, was, therefore, about 50 per cent. The ratio of the maximum demand to the connected load (used) was 54 to 120.

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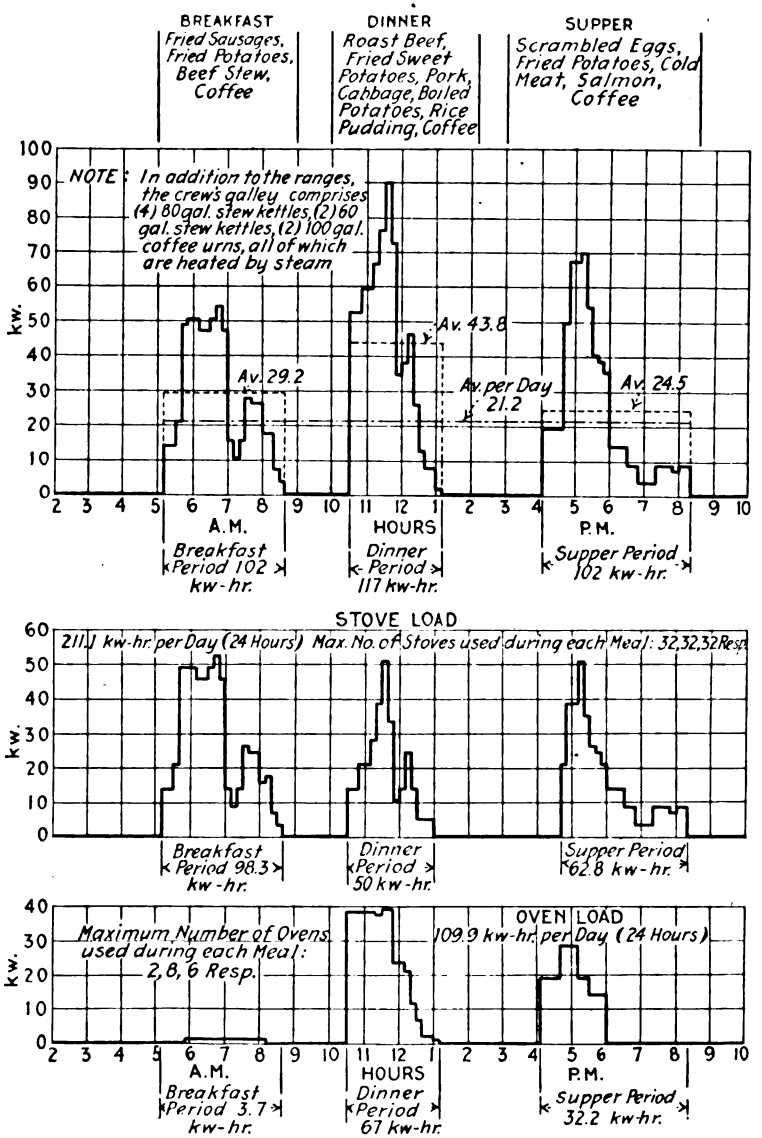
BREAKFAST
Fried Sausages, Fried Potatoes, Beef Stew, Coffee
DINNER
Roast Beef, Fried Sweet Potatoes, Pork, Cabbage, Boiled Potatoes, Rice Pudding, Coffee
SUPPER
Scrambled Eggs, Fried Potatoes, Cold Meat, Salmon, Coffee
NOTE: In addition to the ranges, the crew's galley comprises (4) 80 gal. stew kettles, (2) 60 gal. stew kettles, (2) 100 gal. coffee urns, all of which are heated by steam
kw.
Av. 29.2
Av. 43.8
Av. per Day 21.2
Av. 24.5
A.M.
HOURS
P.M.
Breakfast Period 102 kw-hr.
Dinner Period 117 kw-hr.
Supper Period 102 kw-hr.
STOVE LOAD
211.1 kw-hr. per Day (24 Hours) Max. No. of Stoves used during each Meal: 32,32,32 Resp.
Breakfast Period 98.3 kw-hr.
Dinner Period 50 kw-hr.
Supper Period 62.8 kw-hr.
Maximum Number of Ovens used during each Meal: 2, 8, 6 Resp.
OVEN LOAD
109.9 kw-hr. per Day (24 Hours)
Breakfast Period 3.7 kw-hr.
Dinner Period 67 kw-hr.
Supper Period 32.2 kw-hr.

FIG. 3—TRIAL TRIP OF U. S. S. *Texas*

Ten ranges, 553 men—energy consumption of electric ranges in crew's galley October 29, 1913, (24 hr.) 321 kw-hr.

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The curves in Fig. 3 show a daily load curve for the ranges in the crew's galley indicating a total consumption of 321 kw-hr. The average demand was only 21.2 kw. and the maximum was 90 kw. (during the dinner period), making a load factor of about 24 per cent. Though there are ten ranges installed, only eight ranges were in use, making a total connected load of 240 kw-hr.; but, judging merely from the number of hot plates used that day, only four ranges were necessary. The ratio of the maximum demand to the connected load was, therefore, 90 to 240; whereas if it had been possible for the cooks to operate so as to use each range at its maximum, the ratio would have been 90 to 120.

It will be interesting for comparison here to note that the total electric load of the *Texas* is about 600 kw.

The kilowatt-hour curve shown in Fig. 1, covering a period of five days, was taken from wattmeter readings. The other curves were computed by taking ten minute readings throughout the period of the number of hot plates, ovens, etc. that were in use at each time.

The range used on the *Texas* consists of a cooking surface composed of eight rectangular hot plates having a total useful area of 37 by 24 in. (0.93 by 0.6 m.). Directly under the cooking surface are the two broilers 18 by 24 in. (0.45 by 0.6 m.). Below the broilers are two roasting ovens each of which are 18 by 28 by 16 in. (0.45 by 0.71 by 0.4 m.). Each hot plate takes 1750 watts maximum; each broiler, 4000 watts, and each oven 4800 watts, maximum. The total connected load of the range is, therefore, 31.6 kw. One range oven will roast 75 lb. (34 kg.) of meat at one time.

The bake ovens have a consumption of 16 kw. maximum and a capacity of about 100 loaves.

An important point is that all heating elements of the cooking apparatus are readily replaceable.

## Advantages of Electric Cooking

We shall now sketch briefly an outline of the conditions on board ship which we expect to see realized in the near future.

Compared with the old-fashioned, coal-burning, brick oven, the electric oven shows a most decided advantage. The electric oven will require only two-thirds the time to be heated up to baking temperature. The only effort required from the baker being a turn of the switch, his time and energy, therefore, can be entirely devoted to its proper purpose,—baking good bread for

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passengers or crew. And we must not forget that he will be further aided by motor-driven dough kneaders and other modern bake shop conveniences. There will be no excuse for slack-done or over-done bread or no excuse for stale bread or lack of bread,—as the electric oven will need no attention but an occasional turning of the switch to "high," "low" or "medium" as may be required. The electric oven will not demand any shifting of the loaves in the oven to give some of them the advantage of a hotter place or relieve others from burning, a matter which not only dissipates the cook's time and attention but also considerable heat while the doors are open. Furthermore, one electric oven will do the work of two coal ovens and with more than a corresponding saving in space and a very much greater saving in weight.

The temperature of the bakery will not be appreciably increased as formerly from the waste heat of the radiating brick of the coal oven and the baker's temper and his bread should be as good in the tropics as in the arctics.

What has been said regarding the ship's oven also applies with similar force to the ship's range. Here the compartment previously devoted to the fire and ash box is devoted to an extra roasting oven, increasing the roasting capacity 100 per cent, besides adding special broiling space which provides for two broiling compartments. There is not, of course, much opportunity of increasing the utility of the range top, all of which was formerly active as a cooking surface.

Saving space formerly required for coal boxes, eliminates fuel or ash handling and, therewith, danger from fire or explosion. Absolutely uniform temperatures are secured by the electrical method.

One of the chief advantages in the electric range lies in the broiler, which the coal range entirely lacked. Broiling, like toasting and similar operations, requires a very high degree of heat which should be in the nature of radiated heat from a red hot source; lower temperatures will give the effect of roasting or baking. The coal range often has been the despair of the cook when he wished to do broiling, for that operation required just the right condition of the coals, which is difficult, if not impossible to secure when desired; but the "electric" cook simply turns the switch and instantly the electric coils glow with radiant heat and the sizzling steak at once responds to the broiling operation. Broiling in the coal range also interfered seriously with other

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cooking on the stove top. The broiler will also often be useful in browning the products of the oven and, indeed, will be used as a toaster.

The appliances we have described are chiefly used for what we may call high temperature cooking operations,—broiling, toasting, roasting, baking, frying, grilling, rapid boiling, etc.—and, of course, it is in this direction that electric cooking finds its greatest advantages.

There will be considerable reduction in the depreciation cost of high temperature cooking appliances, as it will no longer be necessary to renew fire boxes, etc. or oven linings and stove tops, because the electric ranges will not *overheat.*

## Advantages of Electric Heating

The problem of heating staterooms, cabins and saloons, by electric heating will be solved by two general forms of heaters, both having the same advantage of perfect control and both effecting a saving in space and weight over that taken by the old style steam piping, not to speak of the absence of leaking, sizzling and pounding steam. Furthermore, there is an advantage in low initial cost, as well as in installation and maintenance cost, besides the feature of portability. This feature not only adds to convenience, but may often enhance the warmth and comfort of the occupants of a room. One of the most important advantages, however, lies in being able to regulate the amount of heat desired, accommodating atmospheric conditions or personal requirements. Overheated atmosphere may be worse than cold and an open window or porthole impractical if not risky.

The two methods are the direct air heating and the luminous. The former is especially adapted to the heating of larger spaces where the air can be circulated over electrically heated coils at moderate temperatures. The ideal electric air heater will have a low operating temperature and a large radiating and proper deflecting surface; the former to avoid any fire risk and the latter to produce a more uniform distribution of heat throughout the room by heating to a less degree a larger amount of air at one time, and to more effectively heat the lower strata of air. The method of heating, itself, is precisely that of the old steam radiator without of course, any disadvantages already referred to.

The other form of air heating, the luminous method, can only be safely secured on shipboard by electric means. This has the advantage but none of the drawbacks, of the cheerful glow of the

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open fireplace, or the comfort of the sun bath. The radiated heat energy does not heat the air directly but passes through it giving up its genial warmth to the material object it strikes. The luminous radiator gives its maximum heat instantly upon the turn of the switch. Indirectly of course, the atmosphere will gradually become heated from its use, but *instantly* a person may be warmed by coming within the range of its glow. It is, therefore, the ideal heater for the stateroom or the bathroom and for auxiliary use in the larger gathering places.

The luminous radiator will, undoubtedly, consist of a specially made incandescent lamp as a heating element; designed, however, for low *luminous* efficiency but for high thermal *efficiency*, emitting a large percentage of infra red radiations.

## Other Electrical Accessories

Perhaps a word should be said in passing for the electric flat iron in the laundry and the soldering iron in the repair shop because as a matter of fact these are in general use and their convenience and success have really been an entering wedge for the adoption of electric cooking and other electric heating on shipboard. On the therapeutic side, the ships surgeon will find in the electric hot water supply, the instrument and bandage sterilizer and body heating pad convenient aids.

## Conclusion

In conclusion, it is our belief that all the handling of fires, of coal and ashes or oil, if done at all, should be done where it belongs down below in the boiler room, not in the galley; and by the stoker, not by the cook. A contented state of mind, whether on the part of passenger or crew, is highly desirable on shipboard; and when the electric cooking has become generally adopted on shipboard, this will be largely assured through well and more easily cooked meals.

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*To be presented at the 295th Meeting of the American Institute of Electrical Engineers, New York. May 19, 1914. Under the auspices of the Committee on Use of Electricity in Marine Work.*

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# ELECTRICITY THE FUTURE POWER FOR STEERING VESSELS

BY H. L. HIBBARD

ABSTRACT OF PAPER

Electrical development in the marine field has been confined in a large measure to the navy, and the best experience with electric steering gears has been obtained from navy installations.

Up to the present time steam has been the universal power for operating steering gears but certain disadvantages are inherent in this system which can be overcome by the electric drive, and additional advantages obtained. The history of electric gears shows that many different schemes have been tried and proved failures owing to faulty designs and imperfectly developed apparatus. At present several different systems are in successful operation.

To obtain full benefit of the advantages possible from an electric drive, much depends on the selection of apparatus with characteristics best suited to the work. The problem of electric drive is largely one of control. The calculations for rudder and motor horse powers must be carefully made, with the proper assumptions for the conditions presented.

Several installations in the navy have shown excellent results; in the case of the battleship *Texas* the data obtained show preliminary calculations were quite accurate. Results obtained seem to justify the prediction that electric steering gears will be used quite generally in the future.

THE MARINE field has probably been one of the most backward in the adoption and development of electrical apparatus owing in part, to natural causes, such as high first cost of electrical over steam machinery, the long familiarity aboard ship with steam machinery, and of the somewhat higher order of care and inspection required for electrical apparatus; but in the main we believe it has been due to the traditional conservatism of the seafearing man and his reluctance to try something new when that which has been used before seemed to answer the purpose, owing in a large measure doubtless to his belief that this policy insured the greatest protection to the lives and property under his care. The most conspicuous exception to this, however, has been the American navy, which is not only a larger user of electrical machinery than the merchant marine, but also leads the navies of the world in this respect.



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During the last few years, however, considerable attention has been given to the development of electricity on board ship, and to many of the auxiliaries we have seen its application, as well as to the electric propulsion of ships, which is now also being given careful consideration. One of the auxiliaries of the greatest importance to the operation of the ship and which also involves some of the most interesting engineering problems, to which electric power and control is now being applied, is the electric steering gear. In line with our previous statement, however, the greatest use of electricity for this purpose has been in the navy, and, therefore, our future statements will refer in a large measure to naval installations of electric steering gears.

## The Steam Steering Gear

Large steamers of the present day are fitted with either the ordinary form of rudder or with a balanced rudder, battleships being almost invariably fitted with the balanced type in order that they may maneuver more quickly. Fig. 1 illustrates the general arrangement of a steering gear controlled by a steam engine on a war ship operating a partially balanced rudder.

Practically all steamers except those of the smallest size at the present time make use of steam power for moving the rudder and in addition to this power drive, most equipments include provision for steering by hand either through handwheels, geared to the steering gear or by block and tackle to the tiller. The possibility of accident to the prime mover and the importance of avoiding a complete breakdown renders the addition of the manual drive necessary, although the rate of turning with the hand gear is, of course, much slower than with power.

The successful introduction of steam power for operating the rudder was made about 1866, by McFarlan Grey. A steam gear designed by him was placed on the " Great Eastern " and the ease with which steering could be done under the new power as contrasted with the old hand method, led to its rapid adoption on all classes of steamers. Improvements have, of course, been made in details, better engines being now made than formerly and better control of them obtained, but, nevertheless, the present steam equipment does not vary greatly from the first one installed.

The control of the valve of the steam engine from the bridge has been accomplished in various ways, in some cases by direct shafting and gears from the steering wheel, in others by wire

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rope transmissions called tiller ropes, and in other installations, particularly of large capacity, by hydraulic telemotors. In practically all cases, however, the control has been by what has been known as the follow-up system, in which the arrangement of valve gear is such that the steam is cut off and the rudder

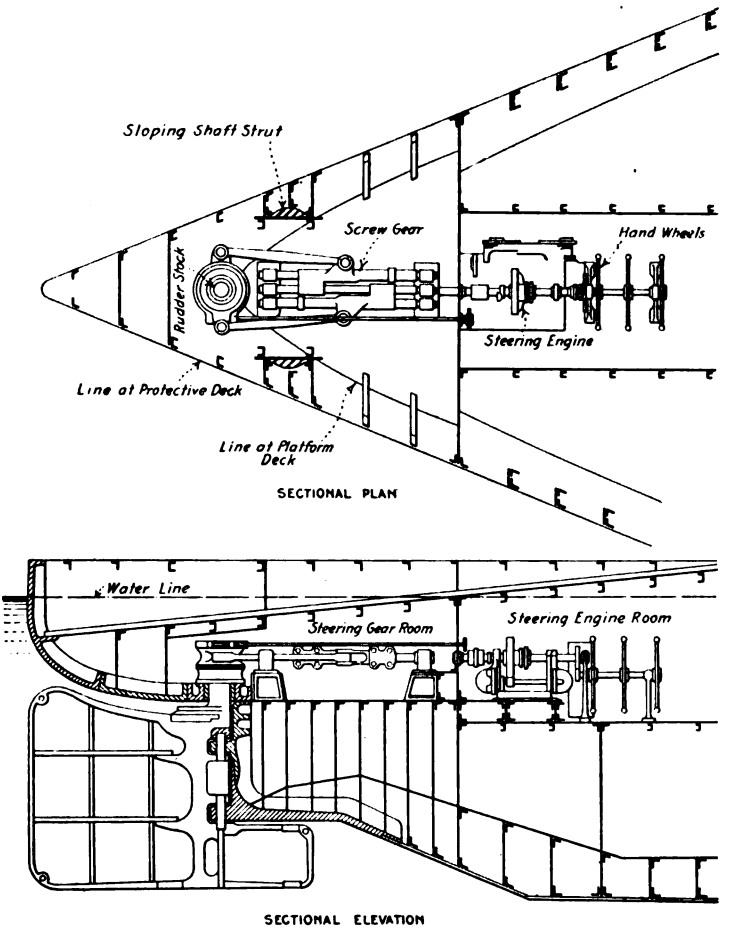


FIG. 1—STEERING ARRANGEMENT OF A WARSHIP OPERATING A PARTIALLY BALANCED RUDDER.

stopped at the angle corresponding to the position at which the helmsman has set his steering wheel. With this arrangement the helmsman turns his wheel to the angle desired as shown by the indicator on the steering stand, and without further operation of the wheel the rudder moves to this point and is automatically

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stopped. This system of control, we believe, has been used in practically all classes of vessels with the possible exception of some large river steamers and has been so generally used for many years as to be, in the mind of the mariner, an integral part of a steering mechanism.

Notwithstanding the general popularity of the steam drive and the excellent service which it has performed for years on thousands of vessels, there are certain disadvantages which are inherent in the system, some of which are as follows:

1. With the boilers near the center of the ship and with the steering engine usually at the stern or in some cases way forward, long and expensive lines of steam piping are required, and a careful design for the leads of piping must be made in order to clear stowage in store rooms, ammunition or other spaces through which they must run. They must be well insulated to avoid heavy condensation losses in the steam, as well as to reduce as much as possible the rise in temperature of spaces, especially powder magazines on war vessels. Even the weight of the piping, lagging, bulkhead fittings, etc. is often a considerable item, and in the case of a battleship this will amount to about three tons, being equal to about 45 per cent of the weight of the steering engine itself.

2. Considerable steam is wasted due to valve setting, it being common practice to set the valves of the steam engine so that even when the rudder is at rest a considerable amount of steam is blowing through the engine. The steam steering engine usually takes steam full stroke and for this and other reasons is an exceedingly inefficient mechanism.

3. The engine must be designed to do the maximum work required of it, that is, all parts of the engine must be of sufficient size and strength to develop the power required at the maximum rudder angle, which is reached but very infrequently in ordinary steering. The engine does not lend itself to overloads as does an electric motor which point is of the greatest importance and will be given special consideration later.

4. The steam engine is provided with reciprocating parts which are subject to severe stresses when the engine speeds up due to sudden decrease of load on the rudder as it is moved back to a central position. These reciprocating parts do not produce a uniform torque, as in the case of a rotating armature, and they furthermore are the source of considerable vibration in the operation of the gear. When in harbors the steam engine

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requires turning over at rather frequent intervals to prevent piston, cylinders, etc. from becoming rusty.

5. The mechanical connections from the bridge to the engine valve are a considerable source of trouble, and wire rope leads frequently wear out. The necessity of running these mechanical connections through compartments and watertight bulkheads is the source of difficulties in the construction of the ship, and in the case of wire ropes, there must be continual care exercised to keep the tubes through which they pass filled with grease, reducing the friction wear to a minimum. If these mechanical parts are not kept in excellent condition the friction causes the steering wheel to be operated with considerable effort and breakage of these parts has not been an uncommon occurrence.

## Results to be Accomplished by the Use of Electric Drive

With the electric gear it is not only possible to overcome, at least in a great measure, the disadvantages enumerated above for the steam engine, but it is also possible to obtain a flexibility, simplicity and accuracy of control not permissible with the steam gear. The results to be accomplished by the installation of the electric steering gears are, therefore:

1. The reduction of the weight and space occupied by the driving mechanism;

2. The suppression of heat in the spaces, adjacent to the gear;

3. The elimination of accidents which may occur in the bursting of steam pipes;

4. The reduction of vibration and noise and increase in habitability, due to these factors;

5. The obtaining of a mechanism very much more efficient in its operation than the steam equipments;

6. The simplification of the means of controlling the mechanism from the bridge with increase in the ease of operation to the helmsman;

7. The increase in rapidity and accuracy of response of the rudder to the movements of the controlling mechanism.

## History of Electric Gears

The subject of electric steering gears has been given some attention by engineers for the past 15 or 20 years but within recent years only has the matter been given sufficient attention or the electrical apparatus developed to such a point as to per-

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mit of successful results being attained. Several electric steering gears of different types have been tried in foreign navies, but it is not known whether any of them have proved completely satisfactory. In a great many cases after being thoroughly tried out they have been stripped and the steam gear again used, some doubtless being defective in design and some in the perfection of details, but others failed due in a large measure to flaws in the controlling apparatus.

At the present time motors and controlling appliances have been developed to such a point as to permit readily of the solution of the problems involved and also to render their performance reliable and trustworthy. The main feature in the electric steering gear has, however, become one of control, and too much emphasis cannot be laid on this point. This problem of control has been attacked by several radically different schemes, the principal ones being outlined below.

Direct current is used universally on board ship, with pressures varying from 80 to 220 volts; the present standard in the American navy is 125 volts with many of the older ships provided with 80-volt equipments, while in the German navy the voltage is 220, and the same is now being considered by the U. S. naval authorities and has recently been adopted on one of the latest battleships as a trial experiment. It is not necessary, furthermore, to give consideration to the use of alternating current motors for operation of steering gears, this current not being employed to any extent on shipboard, and such motors would not give the varying torque and speed characteristics which are here especially desirable.

One of the earliest electric steering gear systems considered in this country was known as the Van Duzer-Mason system and was patented about 1893 and is described in the Proceedings of the U. S. Naval Institute of that year. This system contemplated the use of a motor direct connected to the rudder mechanism and its operation controlled by a simple form of controlling device operated on the follow-up system, but so arranged as to follow up at only a limited number of definite angles of rudder travel and produced, therefore, a very coarse control. It is not known on what vessels this scheme may have ever been tried.

Several systems involving the use of magnetic clutches between the motor and rudder gear and of differentially controlled mechanisms have been tried, but for various reasons have not proved successful.

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One of the first successful electric steering gears is that designed by Mr. Mathias Pfatischer and known as the Pfatischer system. This gear was placed on eight of the Imperial Russian naval vessels, a number of which were destroyed or captured by the Japanese during the recent Russo-Japanese war. It was also installed on two large liners built in this country for the Pacific trade and has been in constant use since 1902 on the liner *Finnland*. One equipment has also been installed by the U. S. Navy on the cruiser *Montgomery* and we understand its operation has been generally quite satisfactory.

This system generally employs a shunt motor for operating the rudder and which is controlled with the varying voltage system by a motor generator set especially supplied for the purpose. The field of the generator or generator exciter, is controlled from the steering stand at the bridge on the Wheatstone bridge principle, the bridge being formed by one rheostat located at and operated by the steering stand and the other located at and operated from the rudder crosshead. The unbalancing of the bridge rheostat by the movement of the wheel gives current to the generator field and therefore, voltage and current to the rudder motor. The balancing of the bridge again by the movement of the rudder crosshead cuts off current from the generator field and the motor is stopped, constituting an electric follow-up control.

Objections which may be offered to this system are the size, weight and cost of the motor generator set, which furthermore, is always in rotation even though the rudder is at rest, and the no-load current of this set is an appreciable amount, being as much as 25 to 30 amperes on sets as small as 25 h.p. With this type of follow-up also the available power of the rudder motor is proportional to the unbalancing of the Wheatstone bridge and approaches zero as the balanced position is reached, which is the point frequently where the maximum torque is desirable, and the result must be the installation of a motor larger than would otherwise be necessary.

Several years ago the Navy Department became interested in the question of steering its ships by electricity owing to the possibilities presented of effecting the economies outlined above for the electric gear. In about 1902 the Department devised a steering gear operated on the follow-up system, and purchased apparatus of different manufacturers to effect an installation on one of the small monitors which had been recently constructed.

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The results obtained from this equipment were not satisfactory. The question, however, remained under discussion for a number of years until about 1909 when a contract was placed for supplying an electric steering gear for the Cruiser *Des Moines* as an auxiliary to the steam engine outfit. For this purpose the use of an electric motor taking its power directly from the dynamo mains and operated by a powerful automatic controller, thus eliminating the necessity of a motor generator outfit, was advocated. The contract specified that no payments should be made unless the gear proved itself satisfactory in service and in the event of its failure was to be removed by the contractor at his expense. The contract further required the control of the motor to be similar to that of the steam engine, *i.e.*, the follow-up system must be employed, and to accomplish this a small follow-up drum controller was provided in the steering engine room and operated differentially by the ship's tiller rope from the wheel on the bridge and the motor driving shaft.

The preliminary trials of this arrangement of gear were quite successful although the writer found upon going aboard the vessel before the trials, that the officers and crew were prejudiced against the electric gear and considered it an unwelcome visitor on their vessel. After the successful preliminary trials of the follow-up gear the prejudice was overcome and it was then suggested that a non-follow-up type of control would be much simpler and easier to operate, but the reply was made that officers and men had steered with the follow-up system for years and it was foolhardy to think of adopting any other type. After considerable persuasion, however, permission was granted to install on the bridge a small reversing switch controller operating the main controller through four small wires and thus entirely cutting out of the operation the steering wheel and the tiller rope connections. After about a month's trial of this system of control the first report to the Department states in effect that the quartermaster and helmsmen learned to steer by this new method in about five minutes and now much preferred it to the old wheel control. Steering by the non-follow-up system on this vessel, therefore, became the prevailing fashion.

Although the reports from the *Des Moines* were of a satisfactory nature, the Navy Department was still naturally doubtful about the use of electric steering equipments, especially as regards the elimination of the follow-up principle. It was decided, therefore, to install such a gear as this on the scout cruiser

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*Chester* to be operated only by the non-follow-up system, and remove the steam gear entirely in order that confirming opinions might be obtained of abandoning the time-honored follow-up control and of steering naval vessels by electricity. Contract was, therefore, placed for the installation of a similar equipment of 75 h.p. on the *Chester* as against the *Des Moines*' 40 h.p. equipment, and this installation was completed the early part of 1912, about two and one-half years after the first installation had been made on the *Des Moines*. The motor with disk brake for the *Chester's* equipment is shown in Fig. 2.

Since this time installations of the same type of gear of 150 h.p. capacity have been made on the battleships *New York* and *Texas*. A further description of these equipments and of many of the results obtained will be given later.

Other installations of electric steering gears have recently been effected by another manufacturer on the Argentine battleships *Rivadavia* and *Moreno* which are just reaching completion at shipyards in this country. These equipments consist of a 150-h.p. motor, 400 to 600 rev. per min., operated with combined rheostatic and field control. The motor operates the rudder at a lower rate of speed than the steering gear engine, to which it is considered an auxiliary, the requirements being hardover to hardover in 40 sec. The motor in question is shown in Fig. 3.

The controller consists of a contactor panel provided with four reversing contactors, a dynamic brake contactor, five accelerating contactors and other small contactors for controlling the field strength and the electromechanical brake.

The master controller is driven by a differential gear in order to provide the follow-up feature. Transmission from the steering wheel to the steering room is accomplished by hydraulic telemotor or wire ropes that are used for the steam engine control. The steam valve may be disengaged by a clutch, and the part of the differential gear, which operates the controller, connected in place of it, and the other part of the differential gear is connected to the steering gear itself. When the controller is turned to a certain point by the steering wheel, the motor begins to turn and will continue to turn until the action of the differential gear, driven by the steering gear itself, turns the controller to the " off " position and stops the motor.

The first position of the controller closes the proper reversing contactors and the current passes through the armature and all of the starting rheostat. The first accelerating contactor then

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closes, and after the motor has speeded up sufficiently the next contactor automatically closes, allowing the remaining three to follow quickly after each other, bringing the motor up to the speed corresponding to the full field strength. If the controller is turned further than this, one of the field contactors is opened and the field weakened; a little further motion of the controller opens the second field contactor still further increasing the speed.

A limit switch, carried on the same shaft as the master controller cylinder, automatically strengthens the field of the motor when the rudder has been turned to a certain definite angle from the mid position, and at a greater angle the field is strengthened still more, bringing it up to its full field strength. This provides an increased torque per ampere when the rudder is a considerable angle from the mid-ship position.

As the rudder returns to the position for which the steering wheel is set, the controller is turned to the " off " position, and if the rudder should be inside of the limits of 10 deg. either side it will be running at full speed. Just before the " off " position is reached the field is strengthened by one contactor. This increase of field strength causes a current to flow from the motor armature into the line, exerting a dynamic braking effect and reducing the speed of the motor. A moment later the field is strengthened again with the same effect, so that at the instant the main contactors open and the motor is disconnected from the line, the speed has been considerably reduced. The dynamic brake is then applied by the action of the proper contactor and the electromechanical brake follows an instant later.

As is later shown, the use of a compound winding exerts a greater torque per ampere with heavy loads, but owing perhaps to the relatively high speed of the armature and the necessity of very accurate stopping with the follow-up control, it seems to have been considered advisable to produce a slowing down effect before the brakes were applied. For that reason a shunt field was used on these equipments, which can be strengthened just before disconnecting from the line. The motor is provided with a small amount of series field winding but it is essentially, in its characteristics, a shunt motor.

The limit switch, besides performing the function of strengthening the field at certain positions of the rudder, will also cut off the power at the end of its movement if it is not already cut off by the movement of the controller. An overload relay is provided, which re-inserts the starting resistance in the armature

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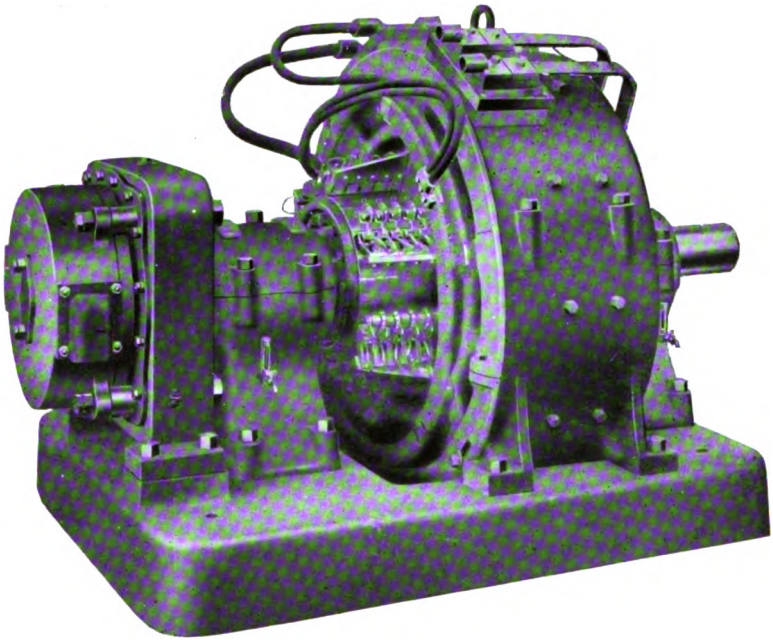

FIG. 2 [HIBBARD]

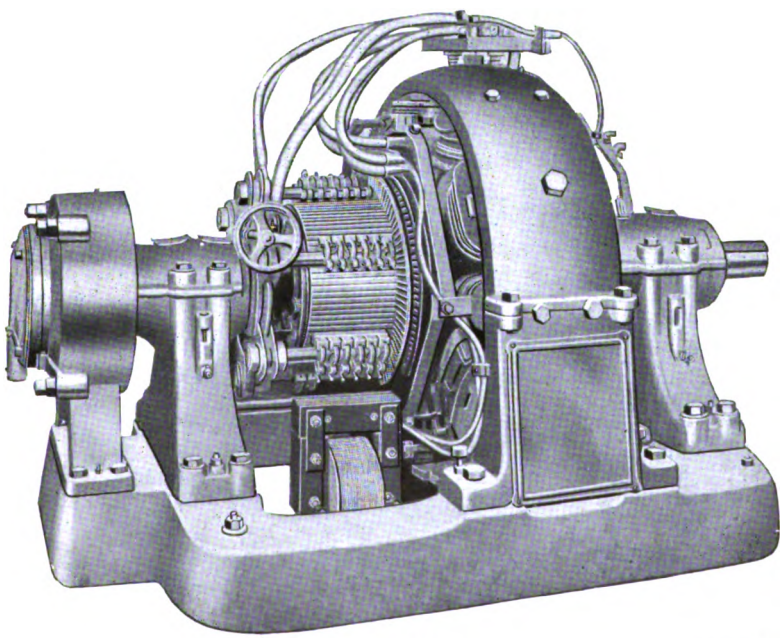

FIG. 3 [HIBBARD]

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FIG. 5 [HIBBARD]

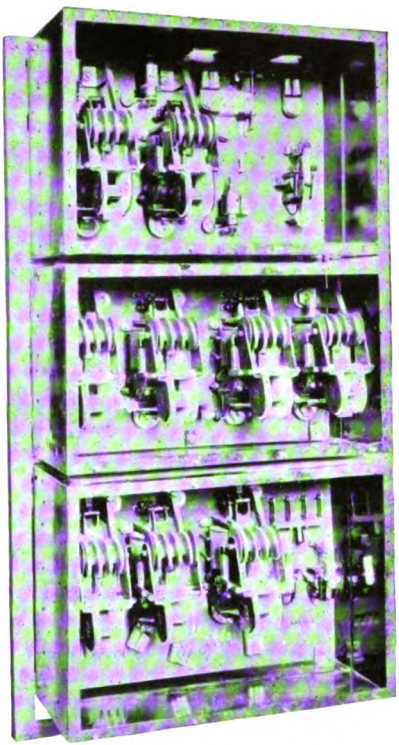

FIG. 6 [HIBBARD]

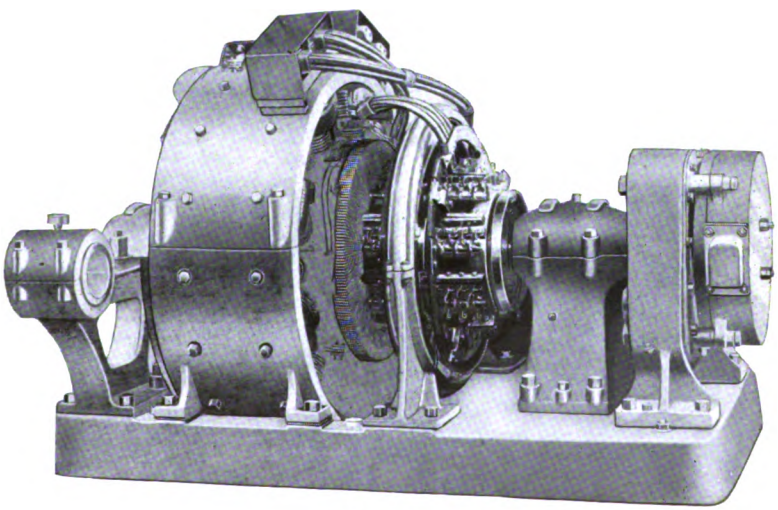

FIG. 8 [HIBBARD]

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circuit in case of overload instead of interrupting the circuit entirely.

We believe these equipments have not yet been tried out in service and we cannot, therefore, comment on results obtained.

The same company is also providing an electric steering gear for the American navy, which is to operate the rudder in the same time as required of the steam engine. The equipment consists of a rudder motor, motor generator, switchboard, steering stands, selective switch and limit switch. The speed of the motor is controlled by varying the field strength of the generator according to the variable-voltage system and the system has no follow-up device. The motor is rated at 350 h.p. and when operating at rated voltage and full load, has a speed of 250 rev. per min.

The motor generator is rated at 290 kw. output and runs at a speed of 1000 rev. per min. The motor has an accumlative compound winding and the generator a differential compound winding, so that the extreme overloads of voltage on the generator will be reduced both by reduction of speed and by the demagnetizing effect on the generator field; also the reduction of speed will deliver considerable energy for a few seconds to the generator circuit. The motor of the set is wound for 120 volts to agree with the ship's voltage, but the generator and the motor which moves the rudder are wound 250 volts. The steering gear motor is compound wound, taking series current from the armature of the motor driving the motor generator, and the shunt field is strengthened by a relay at a definite over load on the motor.

There are four steering stands; three of them forward and one aft, anyone of which may be connected to the panel by means of a selective switch.

The controlling panel contains, the necessary contractors for starting up the motor of the motor generator set, as well as an ammeter and an overload relay, for the generator the necessary field switches and ammeter and voltmeter, also the motor field relay for strengthening the field of the steering gear motor and a step back relay which inserts resistance into the field of the generator in case of excessive overload, performing the same purpose as the overload relay in the rheostatic system previously described.

The various steering stands have three speed positions in each direction; in the first, the field of the generator is excited to give a low voltage for slow speed; the next step strengthens the

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field, and the next step fully excites the generator field, giving full speed of the motor.

The limit switch, which is operated by the steering gear, is provided to cut off power at an extreme movement in either direction without interfering with the return motion after the steering stand is reversed.

In connection with this system, the same criticism may be offered as regards size, weight and power required to operate the motor generator, as was mentioned in case of the Pfatischer system.

### Description of 150 h.p. System on Battleship *Texas*

It is not the purpose of this paper to draw close comparisons between the features and merits of the several electric systems of different manufacturers which have been proposed or installed and which are at present receiving the close attention of the Navy Department and others interested, but rather to point out the salient features of these different systems. Our future remarks apply largely to the system previously referred to, taking power directly from the dynamo mains, with which the writer is most familiar and from which also our data have been principally obtained. As an illustration of this system and of many of the points to be covered in the design of an electric steering gear we give a description of the apparatus and design of the installation on the battleships *Texas* and *New York*.

The electric installation on the *Texas* and *New York* (and with few minor differences that of the *Des Moines* and *Chester*, later transferred to the *Mississippi*, were exactly the same except as to reduction in horse power) includes the electric motor with disk brake installed in the steering motor compartment as illustrated in Fig. 4, the main automatic controller and resistance near the motor, and in the compartment where the screw gear is located a limit switch; master controllers or steering stands are furnished, one on the bridge, one in the conning tower, one in the central control station and one in the steering gear room. The steering stand is shown in Fig. 5, and contains within, a reversing switch for governing the main contactor controller in the motor room. The reversing switch is operated by the lever shown, and closes the circuit to the contactors of the automatic controller through several contact fingers. A latching device retains the lever in the center position, the pressure of the hand on top of the lever releases the latch while a centering

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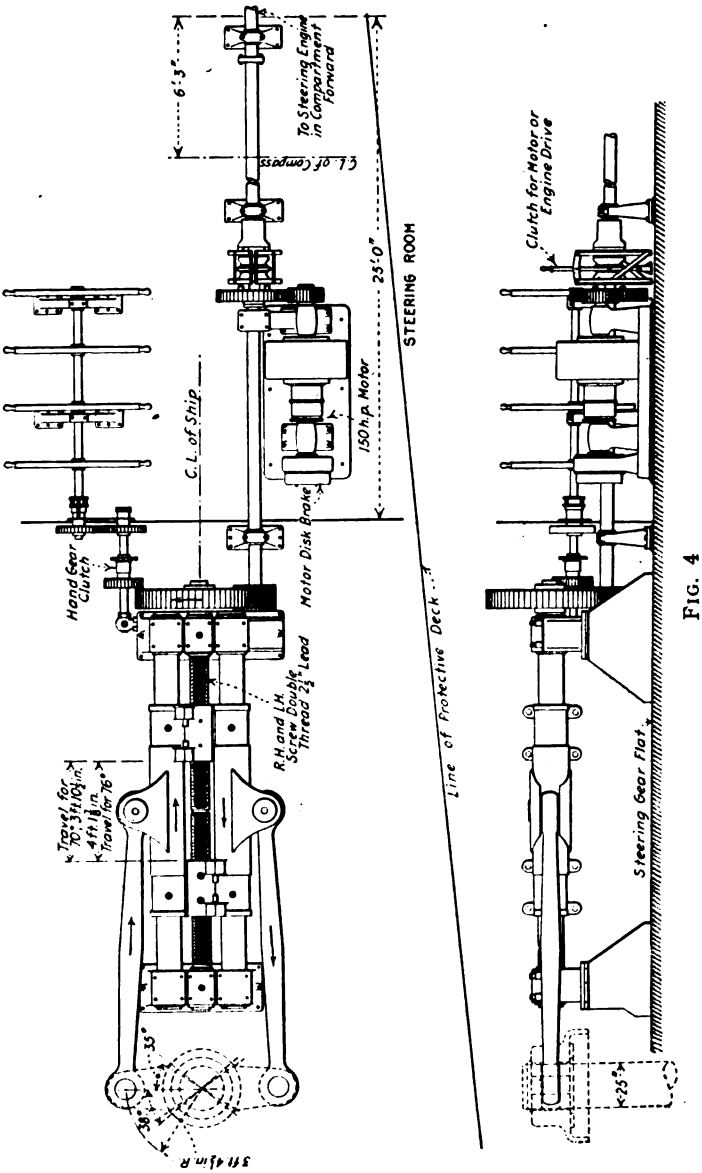


FIG. 4

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spring acts to return the lever to the "off" position, and should the hand be removed from the lever in a running position it will immediately restore itself to the central point when the motor will be instantly stopped.

The stand is so arranged that a small movement of the lever causes the motor to start and run at a slow speed, and further relatively large movements cause the motor to accelerate at once to full speed. Throwing the lever in the reverse direction reverses the rudder motor, so that it is simply necessary to throw the lever to right or left according to direction in which it is desired to move the vessel. About 60 deg. movement of the operating lever in either direction gives full control including starting, stopping, slow and fast speeds and reverse, which feature commends itself to the helmsman especially as quick work is frequently required in maneuvering the vessel. All the metal parts of the steering stand are brass and no magnetic interferences are occasioned by installing it near compasses.

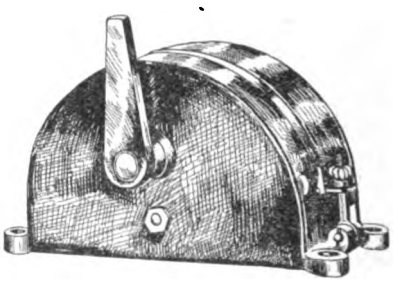

FIG. 7

As no follow-up control is involved the rudder will keep on moving as long as the operating lever is held in the running position and is stopped by the spring return of the lever to the central point which in the possible case of casualty to the helmsman would prove advantageous. Should the rudder for any reason, however, fail to stop before the limits of travel are reached a limit switch shown in Fig. 7 is provided to prevent the jamming of the gear at the hardover positions. For this type of control the position of the rudder is at any instant determined by reference to the helm angle indicator always adjacent to the steering stand.

The main control panel shown in Fig. 6, with its front sheet metal covers removed for the purpose of illustration, provides contactors for the reversal of the armature, for cutting out resistance and accelerating the same, for operating at slow speed and for dynamic braking in the off position. An overload device is provided also which in the event of jamming the gear or other extreme overloads automatically limits the current on the motor to a safe value, and by its use the necessity of circuit breakers

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and fuses, whose blowing would be very dangerous to the operation of such a system, is obviated. The electrically-operated switches not only provide effective means for commutating the motor circuits but they permit the running of wires of a very small section to the steering stations, and as these small pilot wires can all be carried in one lead and conduit, this feature is of the utmost importance.

The switches are of a very strong construction and easily capable of standing the repeated operations of the steering gear. The resistance used in connection with the controller is of the cast grid type and also especially designed for heavy duty. In the lower right hand corner of the cut is shown a small double pole switch which functions as a selective switch for delegating the control to one of two steering stations. This switch was afterward changed in design, however, to provide for control from four or five different stations and so arranged as to make it impossible to steer from more than one station at a time.

The limit switch previously referred to, consists of a small drum controller whose segments are connected in series with the secondary circuits from the main controller, so that when the dogs connected to the traveling nuts of the screw gear engage the lever of the limit switch at the hardover position and open the same, the main contactor switches are opened and the equipment immediately shut down, assisted by dynamic braking and the motor disk brake on the armature shaft. The connections are then such that the rudder can be brought back in the reverse direction by movement of the steering stand lever in that direction, and when the rudder moves away from the extreme limit position the switch is restored to its normal position automatically by a centering spring.

The combined motor and disk brake used in this installation is shown in Fig. 8. The motor is rated at 150 h.p., 250 rev. per min. at 120 volts. The motor is especially designed with overload capacity to operate the rudder under severe conditions, taking care of the power required to operate under the infrequent conditions of rudder at extreme angles with vessels going ahead and backing at full speed. The windings of the motor, about 50 per cent series and 50 per cent shunt, give variable speed and torque characteristics and take advantage of the variation in load from center to hardover positions, giving, a quick response to the rudder especially in the central angles and heavy torques at the extreme angles, and permitting the installation of

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an equipment smaller in rated horse power than would otherwise be required, especially as compared to a steam engine, which point has been previously brought out. The motor is capable of carrying 100 per cent overload for short periods of five minutes or more.

This installation was made as an auxiliary to the steam gear and the requirements for the operation of the rudder were 20 deg. right to 20 deg. left in 20 seconds as against 35 deg. right to left in 20 seconds for the steam engine, and naturally resulting in a smaller equipment than if full duty was required. In the case of a later battleship, the electric gear is required to operate the rudder at the same time as the steam engine and this system has, therefore, been provided for that vessel of 300 h.p. capacity dividing the same between two motors of 150-h.p. each.

### Calculation of Horse Power for the Above Installation

When a vessel is underway and the rudder is at some angle with reference to the keel line of the ship, the water impinging on the rudder surface undergoes a change in momentum, the result of which is dynamic pressure against the rudder and twisting moment about the rudder stock. The center of application of this pressure on the rudder, which varies with each angle, may be found by the use of some empirical formulas. An empirical formula is required as the lines of action of the various streams of water are in different directions at various parts of the rudder due to the shape of the vessel's stern, the influence of friction against the hull, the action of the propellers, etc. In navy work Joessel's formula is principally used, in which:

$d$ = distance of center of pressure from forward edge of rudder
$b$ = breadth of rudder
$a$ = angle made by plane of rudder with line of motion

then $d = 0.195b + 0.305b \sin a$

The twisting moment about the rudder stock is, of course, the product of the total resultant pressure on the rudder area, and the distance $d$ of the point of application of the pressure from the center of the stock.

Let $P$ = total pressure on the rudder in pounds
$V$ = speed of ship in knots
$A$ = area of rudder in square feet
$b$ = horizontal length of rudder plane
$d$ = distance of center of pressure from leading end of rudder

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$a$ = angle of rudder with fore and aft plane

$$\text{then } P = 4.6\,K\,A\,V^2 \times \frac{\sin a}{0.39 + 0.61 \sin a}$$

Usually 35 deg. is the maximum helm angle in which case

$$P = 3.57\,K\,A\,V^2 \qquad d = 0.37\,b$$

For battleships and cruisers $K$ varies from..... 0.60 to 0.75
" gunboats and small slow vessels of 900 tons and up $K$ varies from.....0.55 to 0.65
" torpedo boats and destroyers $K$ varies from.. 0.45 to 0.55

A small coefficient is associated with small vessels, relatively large rudder areas, high speed of the ship and low speed of helm; and a large coefficient is associated with large vessels, relatively small rudder areas, low speed of ship and high speed of helm.

Theoretically the pressure $P$ will increase to an angle of 45 deg. but ordinarily 35 to 40 deg. is the maximum angle of rudder throw. The equipment must be of sufficient size so that when the rudder is near the hardover position sufficient power is available for its operation and this point is, therefore, of chief importance in design and rating of the motor. In the case of the steam engine it is considered that with one-half of the full boiler pressure on one cylinder it should have sufficient torque to move the rudder, the crank of the other cylinder being supposedly temporarily on the dead center.

The pressure $P$ and the center distances $d$ are determined from the above formulas for a number of rudder angles, ranging from center to hardover position and the twisting moment in foot-pounds torque for each angle obtained as the product of the two.

After obtaining the twisting moment on the rudder the turning moment at the prime mover is to be ascertained by taking into account the gearing and friction losses and the angularity of the connecting links in the case of a screw gear.

The calculated, or actual curves if available, of the compound motor which it is desired to use, are then set down, as illustrated in Fig. 9, in the form of percentage speed and load curves, it here being of the greatest importance to select the characteristics of the motor in such a way as to take the greatest advantage of increasing torque with increase in rudder load.

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A curve sheet is then prepared of rudder torque, horse powers and speed, as shown in Fig. 10. The rudder torques are figured for the various angles from the formulas, and the percentage rudder torque curve then calculated, allowance being made, however, in the rudder torques for friction of the rudder stock which in this case has been assumed to be 25 per cent of the normal calculated rudder torque. On curve sheet Fig. 9 it will be noted that the motor characteristics have been chosen to give 280 per cent torque at 100 per cent overload on the motor, and as we desire the motor to have about 100 per cent overload

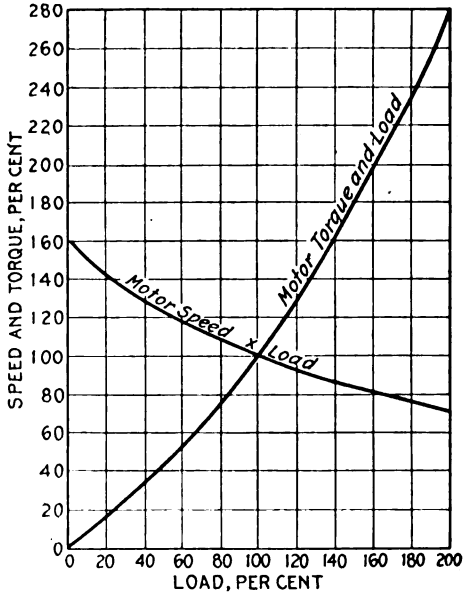


FIG. 9—CALCULATED CURVES FOR ELECTRIC STEERING GEAR FOR U. S. S. *Texas*.

at 35 deg., the total rudder torque at 35 deg. therefore represents 280 per cent torque. The torque at 35 deg. representing 280 per cent, the 100 per cent point of the percentage curve is readily found, as is also the corresponding normal point of calculated rudder torque from which it is obtained by adding the 25 per cent for friction. We have thus obtained the percentage torque curve and the 100 per cent point, where the motor, of the characteristics which we have chosen, reaches 100 per cent torque full load and normal speed and which point, it will be noted, comes at 16 deg. of rudder travel.

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From the motor curves in Fig. 9 the percentage motor speed curve can now be easily figured in per cent of motor speeds for the rudder torque or load at the various angles. Having obtained the percentage-torque and percentage-speed curves the percentage-motor-horse power curve is readily obtained as the product of the two. As it is then necessary to figure in this case the motor speed over the required range of 20 deg. each side of the center, a number of points are taken on the percentage motor speed

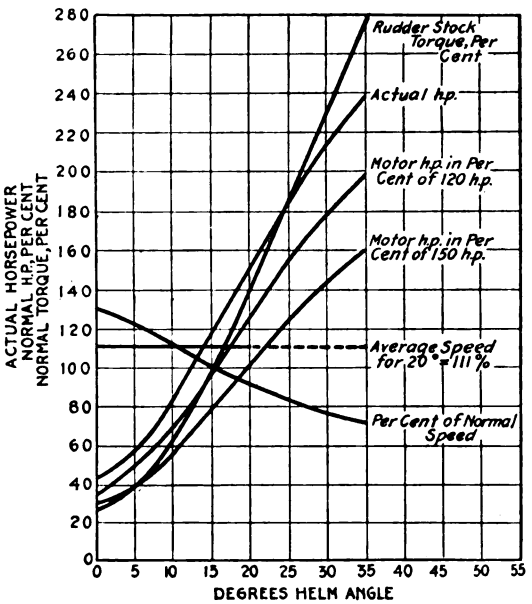


FIG. 10—U. S. S. *Texas*, CALCULATED RUDDER TORQUE AND POWER CURVES.

Maximum rudder torque and power calculated from 1,860,000 ft-lb. at 35 deg. rudder angle.
Friction of rudder stock 25 per cent of normal rudder torque.
Efficiency of gearing 35 per cent.
Compound motor rated 150 h.p. used. (Curves based on 120-h.p. motor).

curves from 0 to 20 deg. and the average obtained, giving us in this case an average motor speed of 111 per cent over a range of 20 deg. of the rudder travel.

The requirement that the rudder must be operated 20 deg. right to 20 deg. left in 20 seconds gives a rudder speed of 0.333 rev. per min. which is the constant average speed of the rudder throughout this range. Dividing this quantity by 111 per cent, a rudder speed of 0.3 rev. per min. at full speed of motor is ob-

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tained and which, it will be noted, obtains at the 16 deg. angle. With this figure as a basis the rudder speed for the other angles of throw are obtained from the per cent speed curve. From the figures of rudder speed and the corresponding torque in pounds-feet at this same angle, the horse power at the rudder stock for each angle is obtained.

From the curve sheet it will be noted that the rudder torque at 35 deg. is 1,860,000 ft-lb. and at 16 deg., 664,500 ft-lb. therefore, the horse power at the rudder stock at 16 deg. of the rudder is 38 as obtained from the following formula.

$$\text{h.p.} = \frac{\text{torque} \times 2\pi \times \text{rev. per min.}}{33{,}000} = \frac{664{,}500 \times 2\pi \times 0.3}{33{,}000} = 38$$

It will be further noted that the assumption has been made in the curve sheet of 35 per cent efficiency for the screw gearing which then gives us a normal horse power of 108.5

From the arrangement of gearing shown in Fig. 4 it will be noted that the screw has a lead of $2\frac{1}{2}$ in. and a radius of yoke $40\frac{1}{2}$ in., therefore, the revolutions of the screw in 10 sec. equals

$$\frac{\sin 20 \text{ deg.} \times 40\frac{1}{2} \text{ in.}}{2\frac{1}{2}} = 5.54 \text{ rev. per min.}$$

For one minute the revolutions of the screw would be $6 \times 5.54$, or 33.24 rev. per min. With an average motor speed of $250 \times 111$ per cent, equal to 277 rev. per min. we have a ratio between a screw shaft and motor speed of 33.24 to 277, which, therefore, gives us an indication of the spur gear ratios which are to be installed between the screw and the motor.

The ratio then determined should now be checked against the torque required to move the rudder at 35 deg. considering the effect of the angularity of the screw gear links, to see if the motor has sufficient torque available for the work under these conditions

$$\text{The torque ratio at 35 deg.} = \frac{40.5 \times \cos 35 \times 2}{2.5} = 83.5$$

$$\text{Therefore, } 83.5 \times \frac{277}{33.24} = 694 \text{ to 1 total ratio at 35 deg.}$$

$$\text{Torque required at 35 deg.} = \frac{1{,}860{,}000}{694} = 2680 \text{ ft-lb.}$$

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Motor torque required at 35 per cent efficiency of gearing

$$\frac{2680}{0.35} = 7675 \text{ ft-lb.}$$

It will be noted the curves were originally based on a 120-h.p. motor, the normal load coming at 16 deg. and 100 per cent overload at 35 per cent, and the calculations above would seem to indicate that this motor would have been sufficient for the service. The government did not wish to see a motor of less than 150-h.p. installed, and this was provided. Later tests on other installations indicated also that more power was required in backing than going ahead and that the 35 per cent efficiency would probably not be obtained, and, therefore, the gear ratio as actually installed was for an average motor speed of about 317 instead of 277 rev. per min. Our gear ratio is therefore, 33.24 to 317 and the torque ratio at 35 deg. would be $83.5 \times \frac{317}{33.24} = 796$ to 1, instead of 694 to 1. Therefore, torque required at 35 deg. $= \frac{1{,}860{,}000}{796} = 2335$ ft-lb. Motor torque required at 35 deg. $= \frac{2335}{0.35} = 6675$ ft-lb.

The curves of actual torque, horse power and speed of the 150-h.p. motor used on the equipment are shown in Fig. 11, and it will be noted that the above calculated torque of 6675 ft-lb. is equivalent to about 80 per cent overload on the motors, coming at a higher point than indicated on the horse power curve in Fig. 10, owing largely to the fact that the motor has slightly different characteristics from those assumed in Fig. 9.

## Some Results Obtained

The results obtained from trial tests and service operation of the installations of this gear have been very satisfactory and the official trials of some of these will be reviewed briefly.

As soon as the *Chester's* installation was completed the early part of 1912 and the vessel put to sea, she was ordered to meet the *Carpathia* at the time of the *Titanic* disaster, and was engaged in this mission about a week during the initial trial of the gear, upon which she had to rely entirely for power steering and the only means of steering from the bridge. Shortly after the

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completion of this duty she was ordered to the ice fields to report the presence of icebergs and was engaged in this work for several weeks. She was then in continuous service until placed in reserve about September of that year and although the performance of her electric gear had been most satisfactory, the gear was then removed and installed on the battleship *Mississippi* and the *Chester's* steam gear replaced, owing to the fact that this vessel

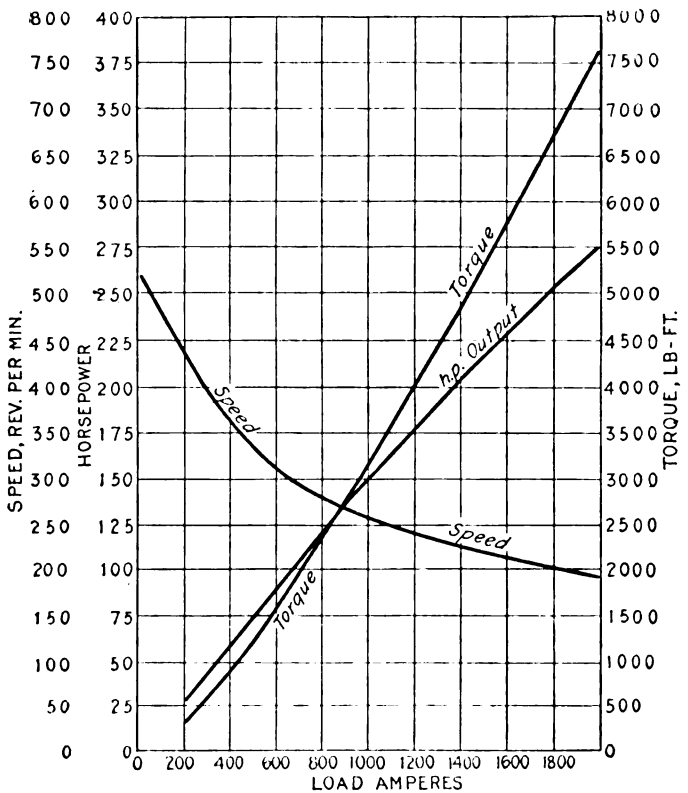


FIG. 11—ACTUAL CURVES—150 H.P. 120-VOLT, 250-REV. PER MIN., COMPOUND WOUND, STEERING-GEAR MOTOR, U. S. S. *Texas*.

was supplied with a limited dynamo capacity. As the Department decided it inadvisable to increase her dynamo capacity this procedure was necessary.

As a result of these trials and experiments on the *Chester* the commanding officer of that vessel reported that he considered this steering gear device unusually satisfactory, and an improvement on the steam gear with telemotor control:

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1. In accuracy of steering
2. In the ease of operation for the helmsman
3. In the vibration of the ship
4. In the heat and moisture of the after part of the ship.

He further stated that he was surprised to see how accurately and with what little motion of the ship it was possible to steer, and that the response of the rudder to the movement of the master switch was rapid, and that the helmsmen were able to keep the ship on her course with small angles of helm and very little effort. The executive officer of the same vessel in his comments stated that "From my observation of this steering gear I should say that the non-follow-up master-switch type of control is entirely practical and suitable, and the quartermasters and helmsman all prefer the master-switch control to the old wheel control."

It is, of course, very natural for an old seaman to throw his wheel to port upon receiving an order to starboard his helm, but the above comments show that these seamen are able readily to learn the new method and one of its most natural advantages is that to steer the ship to starboard or port or right and left, as it is now termed by the Navy Department, the helmsman has simply to throw the operating lever in the direction desired, which is the most logical operation to perform and in contradistinction to the old system which was the reverse of a natural tendency.

An analysis of the conditions and of the electrical apparatus provided, indicates quite clearly that the above results would naturally follow especially as compared with the steam gear equipment. The operation of the master switch is naturally easy for the helmsman and there being no lost motion or mechanical parts between the bridge and steering room, the appreciable time lag with the old steam gear is eliminated. This absence of lost motion and the natural rapidity with which a motor, particularly of this design, can be accelerated, gives practically instantaneous response to the motion of the operating lever. Over the center angles of travel also where the major part of the steering is done and load is light, the response would naturally be very prompt and the speed higher than at the extreme angles.

It was further noted by the officers of both the *Des Moines* and *Chester* that there was an appreciable saving in steam consumption over the steam engine, and it should be noted in this connection that with the steam engine some steam is always passing through the engine valves even with the rudder standing

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still, causing a waste of steam in addition to that consumed in the operation of the engine which is naturally of low efficiency. In case of the electric gear, in addition to its natural high efficiency, the motor is started and stopped each time the rudder is started and stopped and the current is entirely cut off when the rudder is at rest.

A small amount of heat is generated in the rheostat control of the motor but it is quite insignificant as compared with that of the steam engine and not sufficient to cause any inconvenience in the compartments adjacent. On the *Des Moines* the officers mess room is located not more than 20 ft. (6 m.) from the steering engine room yet they reported no inconvenience whatever from the heat experienced even in the tropics.

One of the officers on the *Des Moines*, after a cruise through the tropics, reported that with the temperature at 82 deg. fahr. on the bridge that of the steering and engine room was 98 deg. fahr. and the comment was further made which forms a very convincing argument in this connection, that a quartermaster on the vessel had complained that " in the old days when we had steam on here we could dry clothes in the steering engine room in twenty minutes, but now that place is no good for drying clothes."

We are also pleased to include the final comments of this officer Ensign W. A. Edwards, in the article prepared by him for the Naval Institute Proceedings after he had served some time on both the *Des Moines* and *Chester*.

"From the intimate relations which I have had with this method of steering, from the most excellent results which I have seen produced and from the numerous advantages which it seems to possess over any other method in use today, I cannot help but feel that the electric steering gear is up-to-date and furthermore, that it has come to stay."

He further says: " In summation of the above remarks I would say that at the time of the present writing, Nov. 15, 1912, the *Des Moines* has covered 3600 miles (579 km.) in continuous service, most of which was done in the tropics, during which time the electric steering gear was used constantly without a single breakdown of any kind."

With reference to Ensign Edward's above statement, the writer wishes to explain, however, that thereafter a few minor difficulties were experienced with the *Des Moines'* gear due to breakage of certain parts owing to the largely experimental nature of her equipment. The installation was recently overhauled at the

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navy yard, the minor defects in this first installation remedied and the *Des Moines* is again in the tropics with the electric gear as the only means of steering.

The battleship *Texas*, the special description of whose gear is given above, was during the latter part of October on her official trial trip lasting in all about 12 days. As she left the shipyard the steam steering gear was in use and the electric gear not thrown in until about a day later when the vessel was some distance up the coast. Although this electric gear was an entirely new equipment to all those on board and in charge of its operation, it at once made friends and the steam gear from that time until the vessel returned to the shipyard, about ten days later, was not put into operation except for two or three hours to actually try out its operation, and the electric gear was immediately thrown in again after this short steam trial. The power required in the operation of the electric gear, both in tests going full speed ahead and full speed astern are shown on the curve sheet in Fig. 12. In going astern the engine revolutions were about 80 per cent of the revolutions at full speed ahead.

The curves taken from the recording ammeter used during the trials, while giving a good relative indication of the performance of the gear at various points in the rudder travel and under various conditions, cannot be taken as an accurate representation of actual motor values, the meter in question meeting with an accident during the preliminary trials and requiring repairs at sea without an opportunity of careful re-calibration and as compared to portable direct reading test meters which were also used and the dynamo room meters the recording meter shows at times an excess of current values of 25 to 35 per cent. In the case of the peak starting currents, however, the inertia of the switchboard and test meter needles would probably prevent them from reaching as high values as the recording meter which is more sensitive.

Reference to the curve sheet from the recording meter indicates the most severe conditions were imposed at full speed astern. On some of the backing tests the interruptions to the steady flow of the current were caused by the helmsman, when he saw no immediate indication of rudder travel on the helm angle indicator and believed that at the moment the motor was not moving. As a matter of fact, the motor was turning very slowly at the points of interruption until finally about the $22\frac{1}{2}$ deg. rudder position was reached when the motor accelerated quite rapidly. After

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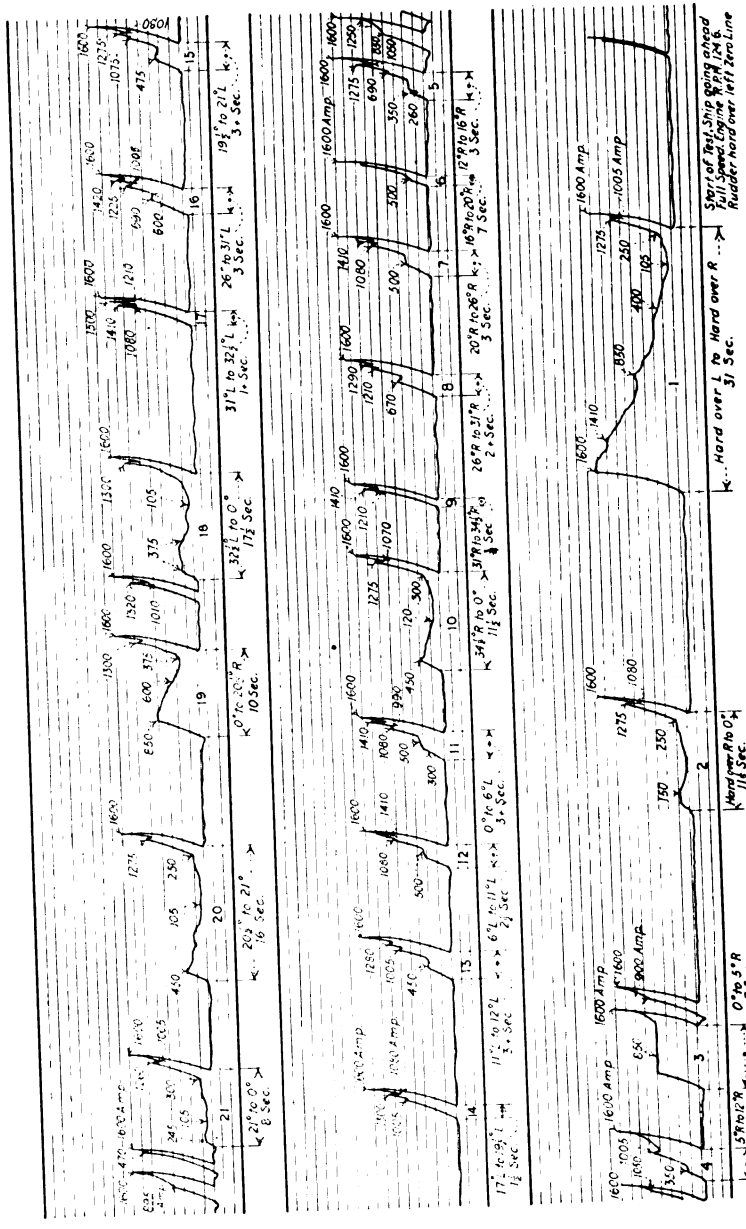
Start of Test. Ship going ahead Full Speed. Engine R.P.M. 124.6. Rudder hard over left Zero Line
Hard over L to Hard over R 31 Sec.
1600 Amp
1005 Amp
900 Amp
0° to 5° R 7 Sec.
Hard over R to 0° 11½ Sec.
5° R to 12° L 4 Sec.
12° L to 6° L 2½ Sec.
6° L to 0° 3 Sec.
0° to 20° R 10 Sec.
20° to 21° 16 Sec.
21° to 0° 8 Sec.
34½° R to 0° 11½ Sec.
0° to 34½° L 11½ Sec.
32½° to 0° 11½ Sec.
31° L to 32½° L 1 Sec.
26° to 31° L 3 Sec.
19½° to 21° L 3 Sec.
26° R to 31° R 2 Sec.
20° R to 26° R 3 Sec.
16° R to 20° R 7 Sec.
12° R to 16° R 3 Sec.

FIG. 12A—GRAPHIC RECORD OF TEST 150-H.P. STEERING GEAR MOTOR, U. S. S. *Texas*
Tests made while off Cape Charles, Va., Line volts-120.

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this the load fell off gradually as the rudder became more nearly parallel with the stream lines. When past the central position the water pressure against the rudder, due to the backward motion of the ship, actually assisted the motor.

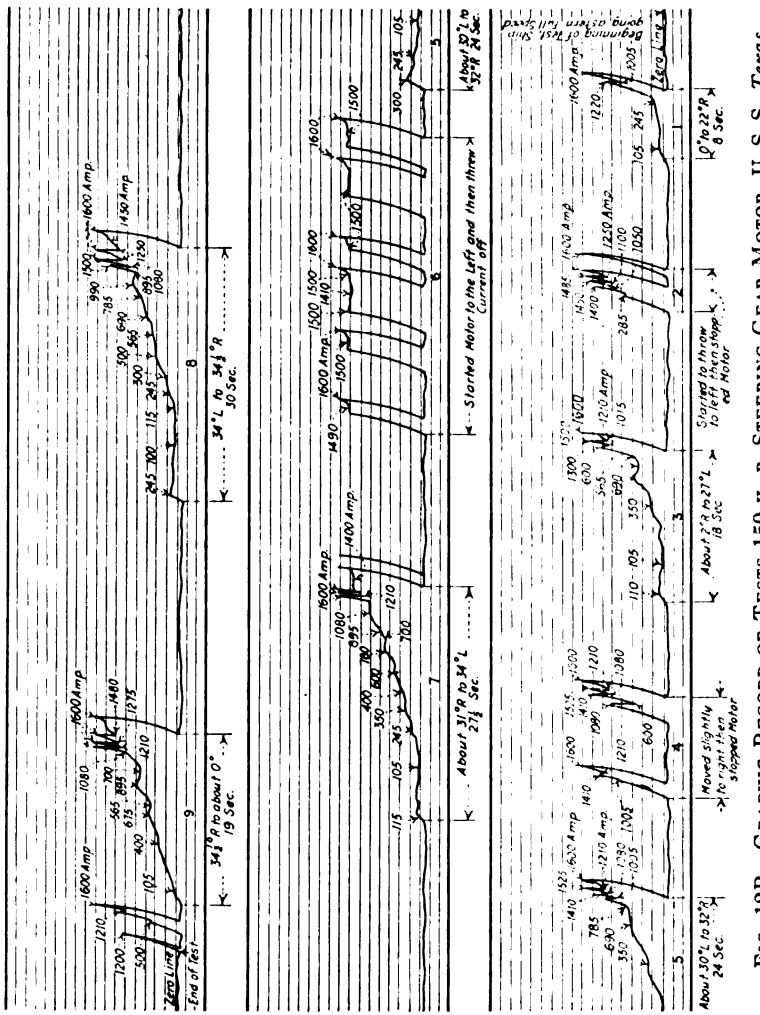
1600 Amp
1450 Amp
1400 Amp
1220 Amp
End of test
Started Motor to the Left and then threw Current off
Moved slightly to right then stopped Motor
Started to throw to left then stopped Motor

FIG. 12B—GRAPHIC RECORD OF TESTS 150-H. P. STEERING GEAR MOTOR, U. S. S. *Texas*
Tests made while off Cape Charles, Va.—Line volts-120.

The rudder was turned from 20 deg. right to 20 deg. left going full speed ahead in about 16½ seconds and from hardover to hardover in about 31 sec. The starting current on the direct-reading meters was about 1250 amperes. (The recording am-

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meter at the same points indicating about 1700 amperes.) This refers to the full speed position with master controller thrown promptly to the last point. About 800 amperes were required on the first or slow-speed notch which was also similarly indicated by the recording meter. On this slow-speed position the motor made about 150 rev. per min.; on the second or full-speed notch the running current frequently varied from 150 to 400 amperes depending upon the position of the rudder with a motor speed of 300 to 400 rev. per min., except at extreme angles, where the current increased rapidly and the motor speed decreased as shown by the curves.

The following data were taken during the official trial trip with the direct reading meters:

| | Ampere Peak | Ampere Steady | Volts |
|---|---|---|---|
| Ship at anchor | | | |
| full speed position | 1220 | 150 | 120 |
| half " " | 1220 | 800 | " |
| Ship full speed ahead, | | | |
| full speed position | 1220 | 110 with stream | " |
| | | 400 against " | " |
| half speed position | 1220 | 800 | " |
| Ship full speed astern | | | |
| half speed position | 1300 | 800 all conditions | " |
| full " " | 1300 | 150 near amidship | " |

Running astern full speed, with motor on full-speed control point, steady amperes started about 1100 turning rudder from hardover position towards center, and dropped to 150 amperes near center line of ship. In starting from hardover position the rudder movement was very slow, increasing as the rudder neared the center line.

The following data were taken on dock trial on the gear before leaving the shipyard.

Line volts 120; amperes max. 1200; steady 116; rev. per min. 410 (second notch).

Time for rudder travel 20 deg. right to 20 deg. left, 15 sec.

Time for rudder travel " hardover to hardover " 70 deg. total, 26 sec.

In connection with the *Texas'* trials it may be stated in general that great satisfaction was expressed by all those on board at the results obtained. And if we assume that 1600 amperes as indicated by the recording meter was the maximum running current required (which is certainly high owing to the errors of the meter explained above), it will be noted, from the curves in Fig. 11, that this corresponds to 60 per cent overload on this 150-h.p. motor or 100 per cent overload on a 120-h.p. motor. It

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therefore appears that there was considerable reserve power available for turning under the extreme conditions, and that the original motor calculations based on 120-h.p. as shown on curve sheet Fig. 10 would have been quite sufficient for the requirements. In connection with the time of $16\frac{1}{2}$ sec. actually obtained to operate the rudder through the 40 deg., it may be stated that in the calculations the total time was taken as twice that required to travel from 0 to 20 deg. and no allowance made for the increased speed of the rudder in traveling with the stream lines from 20 deg. to 0. This accounts largely for the difference between the $16\frac{1}{2}$ sec. obtained and the 20 sec. required.

From the above data and results obtained on tests of other installations it has been found that the power required to turn the rudder changes greatly with the varying conditions which will obtain during the steering of the vessel, and the deductions would appear to be warranted that the maximum torque required when moving the rudder from zero to hardover is greater than that required when moving from about 20 deg. to hardover after running for a brief period at the 20 deg. position. Also that the maximum torque required when moving the rudder from hardover to hardover is greater than that required for moving the rudder from zero to hardover. This it is believed can readily be accounted for by the change in direction of the flow of water against the rudder. If the rudder is at 20 deg. and the vessel turning the direction of the stream lines is not nearly so perpendicular to the plane of the rudder as would be the case if the rudder were at zero and moved to hardover, the hardover position of the rudder being attained, of course, before the vessel had answered its helm. Similarly, if the rudder is at the hardover position and moved immediately to the hardover position in the reverse direction, the direction of flow of the water against the rudder is more nearly perpendicular to its plane than would be the case under either of the conditions mentioned.

From the above it is apparent that no definite deductions can be made as to the efficiency of the mechanism without taking into account the exact conditions under which readings are taken, especially with reference to the angle of stream lines against the rudder, as data taken under various conditions would seem to indicate an efficiency of the mechanism ranging from about 23 to 35 per cent. In the case of the *Texas* our assumption of 35 per cent total efficiency for the gearings was apparently very nearly correct.

The results obtained from various installations show interest-

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ing facts regarding power required to move the rudder when backing. In the case of the *Mississippi* the backing test showed much more power to be required in backing than in going ahead. In the case of the *Texas*, however, the backing power is but little different from that required at full speed ahead, which we assume may be accounted for by a difference in balancing of the rudders for the two vessels, as a difference in the amount of rudder balance would naturally produce a difference in this respect. It is ordinarily assumed that the condition imposed in backing is much more severe than going ahead and the results obtained with the *Texas* on this point, are, therefore, especially interesting.

## Conclusions

In conclusion we believe that the results from trials and service operation of these several installations show that the results previously enumerated to be accomplished by the use of the electric drive have been fully attained. The popularity of the electric gear with those who have been concerned in its operation would seem to have been clearly established, and in addition to a saving in weight, space and efficiency, an ease and accuracy of control has been obtained which has not only eliminated all effort for the helmsman in steering the vessel but has enabled him to keep on the course with smaller and fewer movements of the helm.

The results on the *Texas* have shown that our calculations of the horse power required were fairly accurate and the results obtained have indicated that the capacity actually installed was more than necessary, and considering the fact that the rudder on this vessel was operated throughout the 40 deg. required in 16½ sec. instead of 20, which would have permitted a still greater ratio of gearing to have been installed within the requirements, it is apparent that had such a gearing been provided a motor but little in excess of 100 h.p. rating of this type would have been sufficient for the work. This is in marked contrast to the size and rating of a steam engine which would be necessary for the same service. It may be noted also in this connection what a large proportion of the power is used in the operation of the screw gear itself and where a more efficient type of gear is employed the motor horse power would be still further reduced.

In view of the above it appears to us that the electric gear is up-to-date and has come to stay and it does not seem therefore, too much to predict that electricity will in the future be used generally as the power for the steering of vessels.

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*To be presented at the 296th Meeting of the American Institute of Electrical Engineers, Pittsfield, Mass., May 29, 1914.*

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# EXPERIENCES WITH LINE TRANSFORMERS

BY D. W. ROPER

ABSTRACT OF PAPER

This paper presents an analysis of the transformer troubles for one year on a system having nearly 15,000 transformers installed. This analysis indicates that about 50 per cent of the troubles traceable to the transformer can be eliminated, with no great expense, by some slight changes in the construction details and some improvements in operating methods.

Reference is made to the Standard Specifications for Line Transformers issued by the Bureau of Standards. An experiment on 1600 transformers with the connection board removed or submerged proved that the connection board above oil was responsible for about 60 per cent of the transformer troubles due to lightning. Curves showing the record of burnouts of four different makes of transformers are used as a basis for a discussion of effect of the value placed on continuous service in the selection of transformers.

The results of experiment with improved lightning protection are given, showing how the troubles were reduced by two-thirds. By taking advantage of the results of the two extended experiments, it should be possible to reduce the troubles due to lightning to about 10 per cent or 20 per cent of the troubles heretofore experienced.

Within recent years the line transformer has been developed by the manufacturers into one of the most efficient and reliable pieces of electrical apparatus. It is fortunate for the central station industry that this is the case, as the distributing transformer, next to the meter, is the piece of apparatus nearest to the customer and for that reason its shortcomings would be most readily noticed. While the breakdowns of apparatus or transmission lines in general involve only a very brief interruption to the service, if any, the failure of a transformer generally means an interruption of several hours and especially so if it is located in a sparsely settled region where inter-connection of secondaries is not possible.

That the transformer is a reliable piece of apparatus is evidenced by the fact that last year the total cost of maintenance and repairs of all transformers on the distributing system with



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which the author is connected was about 2 per cent of the value of all transformers at present prices. This figure indicates that any suggestions for improvements would be in the nature of refinements in design or construction, and further, that if such refinements involve any material increase in the price they would be justified only for those companies which place a high value on continuous service to their customers. It appears possible, however, by some slight changes in the details of construction of the transformer and some improvements in operating methods, and without any material additional expense, to eliminate about 50 per cent of the troubles directly traceable to the transformer.

After witnessing the laboratory tests to which the modern transformer can be subjected without injury and after noting the excellent results of the tests for copper loss, iron loss and regulation, it is difficult to state just how further improvements in the transformers might be made. If, however, an operating company having approximately 15,000 line transformers in service adopts continuous service as a bogey score and keeps a careful record of the troubles experienced with the transformers in service, the lines to be followed in making further improvements in the quality of transformers and in their details of construction become somewhat more apparent. A record of the transformer troubles on the system familiar to the writer for the year 1913 is given in Tables I and II.

In discussing possible improvements in the specifications of transformers, it is convenient to use as a basis the standard specifications for transformers issued by the Bureau of Standards as Circular No. 22 in 1911. The introductory paragraph in these specifications reads as follows:

> These specifications have been drawn up with the purpose of providing a standard specification for the purchase of transformers of the type most commonly used both by the government departments and by other purchasers. They have been so drawn as to secure the most serviceable apparatus on the market, and at the same time to admit the regular product of reputable manufacturers. To this end the coöperation of government engineers and of representatives of many of the leading manufacturers has been secured, and it is largely due to help and criticism from these sources that the specifications are representative of the best practise among manufacturers.

It is assumed that these specifications fairly represent the present American practise. The criticisms of the specifications which follow are, therefore, to be considered as being directed against the present practise rather than against the specifications.

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TABLE I

RECORD OF TRANSFORMER TROUBLES FOR THE YEAR 1913.

| Size of transformers | Cause of Troubles | | | | | | Total transformer in service Dec. 31, 1913 |
|---|---|---|---|---|---|---|---|
| | Lightning. | Overloads | Defective. | Grounds and short circuits on secondary wiring | Miscellaneous and unknown | Totals | |
| | Number of cases of trouble. | | | | | | |
| 1 | 4 | – | 2 | – | 2 | 8 | 444 |
| 1.5 | 26 | 2 | 4 | 2 | 12 | 46 | 1,108 |
| 2 | 16 | 2 | 1 | 3 | 6 | 28 | 1,100 |
| 2.5and3 | 21 | 3 | 3 | 2 | 3 | 32 | 2,235 |
| 4 | 13 | 2 | 4 | – | 2 | 21 | 1,056 |
| 5 | 9 | – | 4 | 1 | 6 | 20 | 1,951 |
| 7.5 | 23 | – | 2 | – | 11 | 36 | 2,071 |
| 10 | 9 | – | 2 | 1 | 1 | 13 | 1,626 |
| 15 | 2 | 1 | – | – | – | 3 | 1,113 |
| 20 | 1 | – | – | – | – | 1 | 515 |
| 25 | 1 | – | – | – | – | 1 | 350 |
| 30 | 1 | – | – | – | – | 1 | 207 |
| 37.5and40 | – | 1 | – | – | 1 | 2 | 139 |
| 50 | 2 | 1 | 1 | – | 1 | 5 | 241 |
| 75 | – | – | – | – | – | 0 | 43 |
| 100 | 1 | – | – | – | 2 | 3 | 54 |
| 150 | – | – | – | – | – | 0 | 3 |
| 200 | – | – | – | – | – | 0 | 16 |
| 250 | – | – | – | – | – | 0 | 2 |
| Totals, | 129 | 12 | 23 | 9 | 47 | 220 | 14,274 |

Total capacity, 129,056 kw.

Approximate total value at present prices, $1,000,000

TABLE II

RECORD OF THE FUSES BLOWN AND CUT-OUTS DESTROYED DURING THE YEAR 1913.

| | Due to Lightning | Other Causes | Total |
|---|---|---|---|
| Fuses blown,..... | 911 | 678 | 1,589 |
| Transformers burned out,..... | 129 | 91 | 220 |
| Total cases of trouble,..... | 1,040 | 769 | 1,809 |
| Cut-outs destroyed,..... | 77 | 332 | 409 |
| Ratio of cut-outs destroyed to total cases of trouble..... | 7.4 | 43. | 22.5 |

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The experiences of the author on which this paper is based have been gathered during his connection with the system of the Commonwealth Edison Company in Chicago, and it will be understood, unless otherwise specified, that the experiences and records herein mentioned refer to the system of this company. As this distribution system covers about 125 square miles of territory, including sparsely settled suburban districts, as well as thickly settled urban territory, it is thought that the installation may be regarded as fairly typical.

## Name Plate

The standard specifications require a name plate, but make no mention as to its location. It is the custom of the manufacturers to furnish a name plate on which the lettering is of sufficient size to be read when the transformer is standing on the storeroom floor, but which is somewhat more difficult to read when the transformer is installed on the pole. Securing the correct number of a transformer is made particularly difficult in the larger sizes of transformers because the name plate is located on the front of the case near the top. This puts the name plate so far from the pole that the lineman must unsnap his life belt in order to get in a position where he can read the name plate. If the *safety first* campaign is to be extended to name plates on transformers, they will be located in such a position and the lettering will be of such a size that a lineman, without risking his life, can read the name plate while the transformer is in position on a pole.

## Cases

The standard specifications provide for eyebolts or hooks for handling transformers. The transformers, however, must be handled many times while in the storeroom or in transit from the storeroom to the line. Last year, in Chicago, the number of transformers replaced in order to increase the capacity was equal to the number installed, and the total number handled during the year was over 40 per cent of the number on the lines at the end of the year. Transformers of 5 kw. and smaller capacity comprise over 60 per cent of the total number installed. With the class of help that is used in this work it is very difficult to prevent the men from using the primary or secondary leads as handles. It appears possible for the manufacturers, at no great expense, to fashion the covers of the

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smaller sizes of transformers so as to provide a handle on each side that would be somewhat more convenient for the purpose than the primary leads.

No mention is made of terminals on the primary or secondary leads, but such terminals appear to be quite desirable and are furnished by some manufacturers. It has been suggested that terminals should be located just outside of the porcelain bushings with a solid rod through the bushing. If this could be done, the leads would be so short that there would be no temptation to use them as a handle and, in addition, the solid rod sealed into the bushings would absolutely prevent the siphoning of the oil through the leads. In this manner two of the most aggravating petty annoyances in connection with transformers would be eliminated.

## Cut-Outs

The specifications require two primary cut-outs to be furnished with each transformer, but make no mention as to the qualities desired by these cut-outs, assuming apparently that any cut-outs supplied by the manufacturer will be satisfactory. This assumption is not warranted by experience. The number of cut-outs replaced in a year exceeds the total number of burned-out transformers, indicating that the cut-outs are a less reliable piece of apparatus than the transformers. On the system under discussion the larger sizes of transformers were operated without cut-outs for several years, as it was found that better service could be given to customers in this manner than with the types of cut-outs which were available.

If a company is buying transformers on specifications, the probabilities are that within a few years there will be transformers on hand made by several manufacturers and as several makers furnish their own type of primary cut-out with the transformers, the operating company will soon have several types of cut-outs and must keep in stock and furnish to their troublemen a full line of the various sizes of primary fuses for each of the several makes of transformers. It would be a better plan to have the transformer furnished without cut-outs and for the operating company to secure the cut-outs that are found to be best adapted to its purpose, using one type for the smaller sizes, with one or two additional types of cut-outs for the larger sizes of transformers. Enclosed fuses appear to be the only satisfactory type for the sizes above 40 kw. Some of the points that should be included in the specifications for transformer cut-outs are as follows:

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(1) They should be capable of opening the circuit of the transformer whether the short circuit occurs when the cut-out is cold or when it is heated, due to the load.

(2) It should be impossible for the plug to drop out due to the jarring of the pole, or to be blown out by blowing of the fuse or by short circuits or arcing in the cut-out.

(3) It should have sufficient distance between terminals so that if the fuse blows in a driving rain or wet snow storm, the current will not leak across the cut-out between terminals and destroy the cut-out.

(4) The plug should be provided with a handle of such size and shape that the cut-out can be readily removed by a troubleman when wearing rubber gloves and when the handle is wet with rain or covered with sleet.

(5) The plug should have a shield of such size and shape that when the plug is inserted on a short-circuited transformer the resulting arc will not cause any injury to the troubleman.

(6) The cut-outs for the smaller sizes of transformer should be designed for the use of metal strip fuses. The fuse-holding parts should be designed so that the fuse can be readily replaced.

Some further attention should also be given to the subject of the metal strip fuses for primary cut-outs. In some parts of the city these fuses corrode badly, reducing the cross section of the strip so that the fuses will blow on light loads, and without any apparent trouble in the transformer or on the customer's premises. Some experiments are being made with coated fuses which it is hoped may eliminate this trouble.

## Connection Boards

The specifications require that: "The ends of the primary coils shall be brought to a convenient connection board of porcelain or other suitable material within the case and so arranged that the primary coils may be put in series or in multiple", and also that: "Sufficient oil shall be furnished to completely immerse core, windings, and connection board."

All of the manufacturers do not agree that the terminal board should be submerged. It has even been contended that the connection board could be so designed and located that the lightning would jump across the terminals of the primary coils or from the primary terminals to the cover before the potential across the terminals of the coils could rise sufficiently high to burn out the coils. In looking for evidence bearing on

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this theory it was found that the repair shops had been, for several years, removing the connection boards from all transformers that were re-wound, and that the percentage of troubles on these transformers was less than with new transformers containing connection boards. An investigation was made of all the transformers whose fuses had blown during a severe lightning storm, and signs of arcing at the terminal board were found in a large percentage of the transformers. These facts seemed to indicate that the connection board was the cause of many of the troubles during lightning storms. For the purpose of checking this theory one circuit with a total of about 250 transformers was equipped with transformers having the con-

TABLE III

COMPARATIVE RECORD OF TRANSFORMER TROUBLES DUE TO LIGHTNING WITH TRANSFORMERS HAVING CONNECTION BOARDS ABOVE OIL AND WITH CONNECTION BOARDS REMOVED OR SUBMERGED.

| | | Location of connection boards. | |
|---|---|---|---|
| | | Above oil. | Removed or submerged. |
| 1. Number of transformers,..... | | 9,878 | 1,648 |
| 2. Fuses blown without damage to transformers, | Number | 770 | 56 |
| | Percent | 7.8 | 3.4 |
| 3. Coils burned out,..... | Number | 77 | 10 |
| | Percent | 0.78 | 0.61 |
| 4. Connection boards damaged, leads burned off, etc..... | Number | 36 | 0 |
| | Percent | 0.36 | 0 |
| 5. Total classed as burn-outs, sum of items 3 and 4,..... | Number | 113 | 10 |
| | Percent | 1.14 | 0.61 |
| 6. Total cases of trouble sum of items 2,3 and 4. | Number | 883 | 66 |
| | Percent | 8.95 | 4.01 |

nection boards removed or submerged. Careful records were kept during the succeeding year, but the results were disappointing due apparently to the small number of transformers involved in the experiment. Before the following lightning season arrived, additional circuits were provided with transformers having the connection boards removed or submerged, so that the total number exceeded 1,600 transformers. The scheme of lightning protection was not changed so that the only difference between these transformers and those conforming to standard practise was the removal or submerging of the terminal boards. The results of this experiment for the year 1913 are shown in Table III. In this table, under the heading

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"Fuses blown" are included all cases of trouble which involved blowing of the primary fuse but which left the transformer in operating condition. Under "Burn-outs" are included all transformers which were not in condition for service and had to be replaced. The results as shown in this table indicate that the terminal board above oil is the cause of about 60 per cent of the troubles during lightning storms. The results further indicate that the connection board does not act as a lightning arrester in protecting the transformer coils from damage, but on the contrary that a larger percentage of coils are burned out when transformers are provided with such connection boards above oil than when they are removed or submerged.

It appears, therefore, that the standard specifications have taken a long step forward in specifying that the connection boards must be submerged under oil, but as only a small percentage of the transformers that are provided with connection boards are ever used on 1,000-volt circuits, it is therefore suggested that a further improvement could be made by requiring that transformers for use on 2,000-volt circuits shall be furnished without connection boards and limiting the use of transformers with submerged connection boards to those companies which have 1,000-volt distributing circuits.

## Oil

The standard specifications require that oil be furnished with the transformers. The situation with oil is somewhat similar to that regarding cutouts. Each of the several manufacturers furnishes a different type of oil so that with several makes of transformers in use it would be necessary to keep on hand several kinds of transformer oil and to see that the proper kind of oil was sent out with each transformer. It is possible to obtain a good grade of transformer oil which is entirely suitable for use with all of the several makes of transformers now on the market. Therefore, it appears to be a better practise in purchasing transformers on specifications, to require that they shall be furnished without oil, and to buy the oil separately under proper specifications, provided, however, that the purchaser has suitable facilities for making the necessary tests.

## Design, Materials and Workmanship

The standard specifications contain a paragraph reading as follows: "Action upon these features will be based on the

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requirements of the specifications and observations made while the apparatus is under test." Later in the specifications, under the head of "Basis for Comparing Guarantees", is a paragraph reading as follows:

> In case the proposals offered by different bidders in accordance with these specifications guarantee core losses less than those specified in Table I, each watt of difference shall be evaluated at $0.88 for purposes of comparison. For the same purpose, copper loss shall be evaluated at $0.33 per watt for each watt difference between values specified in Table I and the full-load value guaranteed by the bidder.

An inference that can be readily drawn from these two paragraphs is that having passed the qualifying specifications and having been subjected to a critical examination while the transformer was under test, the several transformers furnished by the various manufacturers are then to be considered of equal value except as to the copper and iron losses and that the relative value of the transformers submitted by the different manufacturers can then be determined by the process of valuation above described. If this assumption was borne out by experience, then we would expect to find that the percentage of burnouts of the various makes of transformers from all causes during the period of the year was approximately equal. In Fig. 1 are shown the results of a recent year's experience with four different makes of transformers. All of the transformers included in these results have passed tests virtually identical with the qualifying specifications above referred to, but as shown by the figure there is a wide range in their ability to withstand the conditions of service. The percentage of burnouts in service for the best transformer was about one-third of the percentage for the rest. It is, therefore, submitted that it should be possible to devise a specification so that there would not be as great a range in quality of the transformers which have passed the specifications.

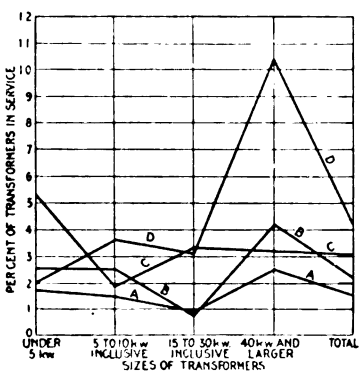


FIG. 1

In order that the cost of the transformer losses and the cost of repairs of the various types may be shown in their proper

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relation to each other, the results shown in Fig. 1 have been applied to the entire installation, assuming that all of the transformers on the system are of each of the several types, and estimates made showing what the total cost of repairs for one year would have been for each of these types of transformers. The iron and copper loss guarantees were also obtained from the same four manufacturers and the total losses for one year were calculated on the assumption that all of the transformers were furnished by each of the several manufacturers. The results of these calculations with different values assumed for the losses and for continuity of service are shown in Tables IV and V. It is not intended that the assumed values should represent the opinion of the author as to the value of these items, but they

TABLE IV

OPERATING COSTS OF FOUR TYPES OF TRANSFORMERS FOR THE YEAR 1913, UNDER ASSUMED CONDITIONS

| | A | B | C | D |
|---|---|---|---|---|
| 1. Cost of iron and copper losses at an assumed value of 1.5 cents per kw-hr | $158,600 | $148,300 | $146,000 | $154,000 |
| 2. Replacing and repairs | 7,700 | 11,100 | 14,900 | 19,800 |
| 3. Estimated loss of income, due to burnouts | 265 | 370 | 510 | 675 |
| 4. Total of items 1, 2 and 3 | $166,565 | $159,770 | $161,410 | $174,475 |
| 5. Loss of prestige, (assumed as 15 times loss of income) | 3,975 | 5,550 | 7,650 | 10,125 |
| 6. Totals of items 4 and 5 | $170,540 | $165,320 | $169,060 | $184,600 |

were assumed over a wide range for the purpose of showing the effect which these values would have in the selection of the best type of transformer for any particular set of conditions. An inspection of these tables shows that the determination by an operating company of the best transformer for its purposes depends upon the values placed by it on the transformer losses and on the continuity of service. If it places a high value on the transformer losses, this feature will determine the best transformer for its purposes. The figures also show that the cost of repairs is a comparatively minor item and that a high value must be placed on continuity of service in order that the savings due to the most reliable transformer may offset the cost of its increased losses.

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## The Protection of Transformers

Transformers while in service must be protected from overloads and from lightning. It is customary to endeavor to protect against overload by means of primary fuses. In practise, a great many minor troubles occur on the premises of customers which will blow the primary fuses. Such troubles should result in the blowing of the secondary fuses on the premises of the customer and the primary fuses should not blow unless there is trouble within the transformer. To secure this result, the transformer must have primary fuses corresponding to several times its rated capacity, so that a slowly increasing load would burn out the transformer. Protection from overloads is best

TABLE V.

Operating costs of Four Types of Transformers for the Year 1913, under Assumed Conditions.

| | A | B | C | D |
|---|---|---|---|---|
| 1. Cost of iron and copper losses at an assumed value of 0.5 cents per kw-hr | $52,860 | $49,450 | $48,690 | $51,500 |
| 2. Replacing-repairs | 7,700 | 11,100 | 14,900 | 19,800 |
| 3. Estimated loss on income, due to burnouts | 265 | 370 | 510 | 675 |
| 4. Totals of items 1, 2 and 3 | $60,825 | $60,920 | $64,100 | $71,975 |
| 5. Loss of prestige, assumed as 15 times loss of income) | 3,975 | 5,550 | 7,650 | 10,125 |
| 6. Totals of items 4 and 5 | $64,800 | $66,470 | $71,750 | $82,100 |

secured by proper records and by occasional tests as a check on the records. During the year 1913, the number of transformers burned out by overload was less than one-tenth of one per cent of the number installed. This record indicates the entire feasibility of protecting transformers against overload by means of the records and tests. The primary fuse should therefore be regarded as a device for disconnecting a defective transformer so as to protect the rest of the service, and not for the protection of the transformer itself from overloads.

Protection of distributing transformers against lightning has apparently not received the attention that it deserves. The record of lightning troubles for the year 1913 is shown in Fig. 2. These results show that the larger sizes of trans-

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formers are comparatively immune from lightning, and that the greatest number of troubles occur with the smaller sizes, that is, the sizes below 10 kw. The number of transformers of these sizes comprise about 70 per cent of the total installation, so that the transformers which are most susceptible to damage by lightning are the most numerous. It is suggested that careful attention by the manufacturers to the primary bushings, the clearance of the primary leads inside the case, the manner of their support and other minor details, would probably result in a material improvement in these records.

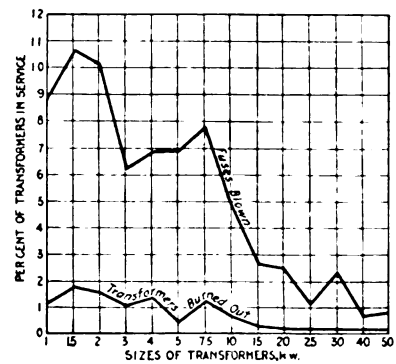


FIG. 2

In addition to the experiments mentioned above, which involved the removal of connection boards from a large number of transformers, some further experiments were made in another area, which consisted in

TABLE VI.

RECORD OF TRANSFORMER TROUBLES DUE TO LIGHTNING, SHOWING THE IMPROVEMENT IN SERVICE DUE TO THE INCREASED LIGHTNING ARRESTER PROTECTION.

| | Ratio of arresters to transformers | |
|---|---|---|
| | 40 per cent | 100 per cent |
| Location of arresters, | On line poles. | On transformer poles. |
| Number of transformers, | 9,878 | 1,560 |
| Fuses blown, Number | 770 | 85 |
| Percent | 7.8 | 5.5 |
| Transformers burned out, Number | 113 | 6 |
| Percent | 1 .15 | 0 .39 |

NOTE: All transformers had Connection boards above oil.

installing lightning arresters upon the same pole with each of a large number of transformers. The remainder of the distributing system in question is protected by arresters not located

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on the transformer poles but scattered over the lines at a distance of about two thousand feet, resulting in a ratio of arresters to transformers of about 40 per cent. The results of these experiments are shown in Table VI.

In that portion of the territory where there was an arrester on the same pole with each transformer, the results to date as compared with the older practise indicate that the percentage of transformers burned out by lightning is reduced by about two-thirds. The several experiments indicate that by the combination of the two schemes and possibly by some further improvements in some details of the transformers and in the design of the lightning arresters, there should be no great difficulty in reducing the percentage of cases of trouble due to lightning to one-fifth, and possibly to one-tenth, of those experienced in former years. It is hoped that more definite and complete information on this subject may be available within another year.

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# EXPERIENCE OF THE PACIFIC GAS AND ELECTRIC CO. WITH THE GROUNDED NEUTRAL

BY J. P. JOLLYMAN, P. M. DOWNING AND F. G. BAUM

ABSTRACT OF PAPER.

The paper gives an outline of the distributing system of the Pacific Gas and Electric Company of California which operates at 60 kv., the transformers being Y-connected, with the neutrals solidly grounded. The company considers the grounded netural system has a number of important advantages with regard to the transformers, the transmission lines, and operation.

The fewer turns of larger capacity of the Y-connected transformers and the fixed lower average voltage to ground greatly increases their reliability.

The maximum voltage on the line insulators with the grounded neutral is never more than 57.7 per cent of the line voltage, and it is possible to maintain polyphase service at a substation on a branch line with only two wires in case one wire should be cut out. This cannot be done on a delta system unless one phase of the system be grounded, which is very undesirable.

With a grounded neutral, a wire down is instantly detected and power must be shut off. In a delta-connected system an arcing ground is often followed by surges which break down the insulation at other points, the cause of this disturbance being the oscillatory character of the arc. In the grounded Y system no such disturbances occur, as the frequency of an arc to ground is the same as that of the system and any damage is confined to the point of failure.

It is also believed that operation with the grounded neutral causes less disturbance in telephone and telegraph lines than would be the case in delta-connected lines.

THE PACIFIC Gas and Electric Company operates a very extensive 60-cycle transmission network in Central California. The 60-kv. system comprises about 1260 miles (2027 km.) of three-phase circuit. It is supplied directly by nine hydroelectric plants having an installed generator capacity of 67,310 kw. and three steam plants having an installed turbo-generator capacity of 68,000 kw. In addition there are 14,300 kw. of steam engine-driven generators in the company's steam plants which are held in reserve. The 100-kv. system which has just been put into operation has one hydroelectric generating station of 25,000 kw. capacity and 109.5 miles (176 km.) of circuit. The entire output is fed into the 60-kv. system through one substation.



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For the purpose of the receipt or delivery of power the 60-kv. system is connected as follows: at Chico to the 60-kv. system of the Northern California Power Company; at Santa Rosa with the 60-kv. system of the Snow Mountain Water and Power Company; at a point near Folsom with the 60-kv. system of the Western States Gas and Electric Company; and at Oakland, through transformers, with the 100-kv. system of the Great Western Power Company.

These connections very considerably increase the length of circuit and total generator capacity connected to the 60-kv. system. The entire 60-kv. and the 100-kv. systems are usually operated in parallel.

The transformers at all the company's own generating stations and at all important substations have their high-tension windings Y-connected with the neutral solidly grounded. The low-tension windings of the generating station transformers are nearly all delta-connected as are also about half of the substation transformers. The remaining substation transformers have both windings Y-connected with solidly grounded neutrals. In most of the substations where the low-tension windings are delta-connected, a switch is provided between the high-tension neutral and the ground, which is normally kept open. This avoids the short-circuiting of one transformer in case of a ground on the transmission system and prevents the substation being cut off from the system by the opening of the protective devices on the high-tension side of the transformers. There are over 225,000 kw. of 60-kv. transformer capacity in the company's own generating plants and substations.

The Northern California Power Company, the Snow Mountain Water and Power Company and the Western States Gas and Electric Company operate their transformers Y-connected with the neutrals solidly grounded. The connection with the Great Western Power Company is through transformers connected delta to delta. This method of connection is not theoretically correct where power is to be fed from the delta-connected transformers into the grounded Y system, because a ground on one wire of the line connecting the delta-connected source of supply with the grounded Y system will impress 173 per cent of normal voltage across the high-tension windings of two of the transformers in the grounded Y banks. The resulting disturbance in the low-tension circuits is very severe. Our experience proves conclusively that this method of connection is not desirable.

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At all generating stations, and at all important junction points and substations the 60-kv. lines are controlled by oil switches. The lines are switched out under any condition of load or short circuit as occasion demands. The lines are also switched on at full voltage. We have operated in this manner for over 10 years and have never had any failures of transformers or of line insulation which could be attributed to this method of operation.

We consider that the grounded-neutral system as compared with the delta system affords the following important advantages:

1. *With Regard to Transformers*: Transformers are wound for only 57.7 per cent of the voltage required in the delta system. The average voltage to the neutral from all points of the windings is 50 per cent of the voltage from line to neutral; that of a delta bank is 69 per cent. The product of the turns times the average voltage to neutral in the Y-connected bank is 41.8 per cent of that in the delta-connected bank. The windings have 173 per cent the current capacity of the windings of a delta transformer.

In addition there is only one line terminal per single-phase transformer, wiring for a spare unit is much simpler and the high-tension windings may be used as auto-transformers in supplying small amounts of power to lower voltage circuits.

The connection between the Pacific Gas and Electric Company's 100-kv. system and the 60-kv. system is made with auto-transformers connected grounded Y. We believe this to be the simplest, most reliable and most efficient connection that can be made between two such systems.

Our transformers have given so little trouble that we have not had much occasion to try to maintain service with only two transformers. We have had no difficulty, however, in carrying loads up to 2000 or 3000 kw. with two transformers.

Our experience confirms our belief that the fewer turns of greater current capacity and the fixed lower average voltage to ground of the transformers greatly increase their reliability.

2. *With Regard to Transmission Lines:* The maximum voltage on the line insulators is fixed and is never more than 57.7 per cent of the line voltage. Ten years ago the pin type insulator was the only type obtainable and the low fixed maximum voltage of the grounded neutral system has unquestionably been of great assistance in securing the best service from this type of insulator.

It is possible to maintain polyphase service at a substation on a branch line with only two wires in the event one wire should be cut out. This cannot be done on a delta system unless one

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phase of the whole system be grounded and this is very undesirable.

3. *With Regard to Operation:* With the neutral grounded, a wire down is instantly detected and power must be immediately cut off. This is exceedingly important where many of the circuits run through thickly settled districts. Inasmuch as practically all our important loads are reached by two lines or are on a loop, service is not more than momentarily interrupted by a failure at one point.

A line of any length may be charged at full voltage without shifting the static neutral. It is impossible to close all phases of a circuit at exactly the same instant. In a delta system the first phase closed will increase the capacity to ground of that phase of the system and thereby draw the static neutral toward that phase. The second phase acts in a similar manner and the static neutral does not return to the center of the delta until the three phases are closed. This sudden shifting of the static neutral is the cause of an unnecessary strain on the insulation of the system. We know of failures from this cause on delta-connected systems.

Finally, and most important of all, is the fact that in extensive high-voltage delta-connected systems a ground is often followed by a disturbance of such power that breakdowns of insulation at other points take place. Such a disturbance generally results in serious damage to apparatus and service. The cause of this type of disturbance is found in the oscillatory character of the arc which takes place from a delta-connected system to ground, together with a large amount of current which will flow in such an arc if the system is extensive. In the event of a ground on a delta-connected system, the charging current, which is a function of the voltage from wire to neutral, will be increased because the neutral is shifted from the center of the delta to one corner. This increase will be about 73 per cent. The current flowing in the arc to ground may be nearly equal to the increased charging current, and this on our 60-kv. system would amount to about 400 amperes. The circuit containing the arc, line reactance and capacity from line to ground tends to oscillate. Such an oscillating arc is very likely to set up disturbances of high power especially when there is any such current as 400 amperes involved. We have seen evidence that such a disturbance may cause high voltage to ground on the wire on which there is an arcing ground. This fact would probably cause the operation of an arcing ground suppressor to be very unreliable.

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Certain districts in which we operate occasionally have heavy fogs which are carried in from the Pacific Ocean by the prevailing westerly winds. It has been our experience in these districts that lines on pin insulators have given better service when operated grounded Y at 60-kv. than when operated delta-connected for a much lower line voltage. It seems probable that the leakage over the insulators in foggy weather was sufficient to set up oscillatory disturbances which caused more trouble than has the higher but more stable line voltage.

We have found that the grounded Y system is entirely free from such disturbances as these. The frequency of an arc to ground is that of the system. Any damage is confined entirely to the point of failure. The short-circuit currents have not caused any damage to generator or transformer windings. Due to the distribution of the sources of power, any given point on the system will have a good many miles of line between it and several of the generating plants. Hence it is doubtful in many cases if more current would flow in a short circuit to ground than would flow to ground if the system were delta-connected. The drop over the lines from the more remote generating plants to a point at which a ground may take place serves to prevent the voltage at points removed from the trouble from dropping to zero, and therefore the service is not seriously interfered with except in the vicinity of the trouble.

We believe that the operation of our system with the neutral grounded causes less disturbance in the circuits, of our neighbors, the telephone and telegraph companies, than would be the case if we operated delta-connected.

Briefly, the induction in parallel telephone or telegraph circuits is caused by any unbalanced currents in the phases of the high-tension circuit, and by the presence of voltage to ground on the line conductors. The last cause is by far the most important because the unbalanced currents during normal operation may be kept very small while the voltage to ground is always high. A ground on the grounded-Y system will not cause much, if any, more current unbalanced than will a ground on a delta-connected system. The unbalanced current is at normal frequency in the grounded-Y system in place of at a very much higher frequency as is usual on the delta-connected system, hence the parallel circuits are not affected so unfavorably. It is our experience that even a considerable amount of unbalanced current at the normal 60-cycle frequency has little noticeable effect on

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parallel telephone circuits. The unbalance will be immediately removed from the grounded-Y system in all cases, whereas a delta-connected system may occasionally be operated a short time with a ground before a final shut-down takes place. The definite limit on the voltage to ground is of very great advantage to the parallel circuit.

## Conclusion

The operation of our high-tension network with the grounded neutral has been entirely satisfactory. We do not believe that we could give as good service, with as high a degree of safety to the public, with any other system.

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# INFLUENCE OF TRANSFORMER CONNECTIONS ON OPERATION

BY LOUIS F. BLUME

ABSTRACT OF PAPER

In this paper the relative advantages and disadvantages in operation of the more important three-phase transformer connections are discussed. Three conditions of operation are given: First, normal; second, operation of a bank with one phase disabled; third, effect of line grounds on operation.

The paper is not complete, particularly in that high-frequency or switching phenomena are not discussed. Its major purpose is to give a fairly adequate presentation of insulation stresses at relatively low frequencies to which transformers are subject in either normal or abnormal conditions of operation. These frequencies include the fundamental or generated frequency and its harmonics and the natural frequency of the system.

The behavior of three-phase auto-transformers under the various conditions of operation given above is also analyzed.

Transformers for use on three-phase systems are in the majority of cases connected either delta-delta or delta-Y, these two being almost universally considered superior to the few other connections which may be used for three-phase transmission. Opinions differ, however, as to their relative merits, and the purpose of this discussion is to analyze some of the factors involved.

*Operation in Case of the Disabling of One Phase.* In the delta-delta connection, operation can be continued by running open delta after removing the disabled phase, under which condition the bank can handle 58 per cent of its original capacity. When, however, there are two or more delta-delta banks operating in parallel, the advantage of open delta operation of one bank becomes less on account of the fact that a mutual relation exists between the loads in the two banks. For example, if one phase of one bank is removed, instead of being able to operate the good bank at 100 per cent capacity and the open delta bank at 58 per cent capacity, making a total of 158 per cent (assuming all transformers alike and that 200 per cent was the original



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total capacity of the two banks) it will only be possible to derive from the five transformers 133 per cent capacity.[1] When two delta-delta banks are operated in parallel with one open delta bank, a total capacity of 233 per cent instead of 258 per cent is obtainable. Thus it is evident that with increasing numbers of delta-delta banks connected in parallel, the advantage of being able to operate any one of them in open delta decreases. This, however, is not a serious objection, because, by placing the proper amount of reactance in series with the weakened phase, the capacity can be considerably increased.

Open delta operation of a three-phase core type transformer is, in the majority of practical cases, not possible, on account of the interlinked magnetic structure.

In delta-Y connections, the disabling of one phase renders the whole bank inoperative, except in the case when it is possible to change the voltage of the line connected to the Y side of the transformers. For example, if a line transmits power from one bank of delta-Y transformers at one end to another bank of Y-delta transformers at the other end, operation can be continued in case of the disability of one phase by changing the Y connection to open delta in both step-up and step-down transformers, thus reducing the transmission line voltage to 58 per cent of its original value. Under this condition the capacity of the transmission line and transformers is reduced to 58 per cent of the original value, which is equal to the capacity obtained in the case of operating one delta-delta transformer bank in open delta. When, however, two or more Y-delta banks are operated in parallel, the disability of one phase renders the whole of one bank inoperative.

*The Effect of Differences in Characteristics of the Transformers Making up a Transformer Bank.* When transformers of slightly different ratios are connected in delta-delta, large circulating currents will result in the delta circuits, depending upon the amount of off ratio and the impedance of the transformers; and when transformers having different impedances are connected for delta-delta operation, the division of load between them will be very unequal. In general, a delta-delta connection is very sensitive to variations in impedances and ratios. A Y-delta bank of transformers is far less sensitive to such variations, and in fact transformers having considerable differ-

1. See article entitled "Delta-Delta Transformer Banks in Multiple," by W. W. Lewis, *General Electric Review*, January, 1912, page 47.

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ences in ratio and impedances can be used to make up a Y-delta bank without appreciably affecting the current or voltage division of the phases. From this it is evident that, in cases where a three-phase bank is to be made up of dissimilar units of equal kilovolt-ampere capacity, more satisfactory operation can be obtained by connecting delta-Y than delta-delta. On the other hand, if the kilovolt-ampere capacities of the units are different, the delta-delta connection will probably result in a greater combined capacity than Y-delta, because in the delta-delta banks the currents will divide to a certain extent, at least in proportion to the kilovolt-ampere capacity of the units, whereas in the Y-delta connection the currents in all three phases are equal.

## Insulation Stresses

The potential stresses on the insulation at fundamental frequency are worthy of consideration and become particularly important in high-voltage transformers. Under normal conditions of operation, that is, when the connected line is free from grounds, the maximum value of these stresses is equal to 58 per cent of line potential. In the delta connection the minimum value of the insulation stress is equal to 29 per cent and occurs at the middle point of the winding, whereas in the Y connection the stress is zero at the neutral end of the winding, and increases uniformly to its maximum value of 58 per cent at the line end These stresses are tabulated below for convenience in comparison, together with corresponding insulation safety factors, the latter being based on the assumption that the windings are insulated to withstand a test equal to twice normal voltage.

TABLE I

Insulation Stresses from High-Voltage Winding to Ground, in Three-Phase Connections, at Fundamental Frequency, under Normal Operating Conditions.

| | Stresses in per cent of line voltage | | | Safety Factor | | |
|---|---|---|---|---|---|---|
| | maximum | minimum | average | maximum | minimum | average |
| delta | 57.7 | 28.8 | 43.2 | 7 | 3.46 | 4.64 |
| Y | 57.7 | 0 | 28.8 | infinity | 3.46 | 7 |

When one terminal of the transformer is grounded, these stresses are all materially increased. Their values at various portions of the winding are shown in Fig. 1. Here high-potential stresses in the insulation from winding to core in per cent

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of the normal line voltage for every portion of the high-voltage winding are plotted as ordinates. The curve shows that the stress in the insulation of delta winding is practically equal to line voltage at all points of the winding, the voltage at the middle point, however, being reduced to 87 per cent of this value. On the other hand, in the Y connection the stress in the winding is graded, being a minimum at the neutral and a maximum at the line end. Three cases are given: Curve *a* shows the condition when the neutral is not grounded; curve *b* shows the condition when the neutral is grounded, and when the line is capable of maintaining normal voltage notwithstanding the short circuit produced by a ground on the line; and curve *c* shows the stresses in delta-Y transformers excited on the delta side and operating with a grounded neutral. A particularly large reduction of stress is obtained in the latter case, the maximum never exceeding 58 per cent of line potential. These stresses, together with their corresponding safety factors, are given in Table II.

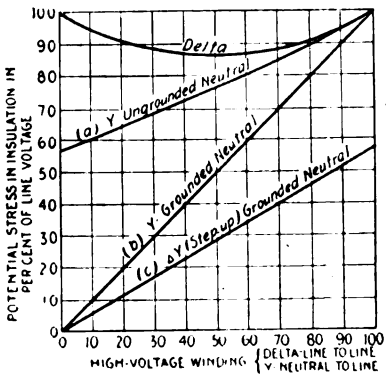


FIG. 1—EFFECT OF GROUNDS ON POTENTIAL STRESSES AT FUNDAMENTAL FREQUENCY ON THREE-PHASE CONNECTIONS

TABLE II

INSULATION STRESSES FROM HIGH-VOLTAGE WINDING TO GROUND, IN THREE-PHASE CONNECTIONS, AT FUNDAMENTAL FREQUENCY, WITH ONE TERMINAL GROUNDED.

| | Stresses in per cent of normal voltage | | | Safety factor | | |
|---|---|---|---|---|---|---|
| | minimum | maximum | average | maximum | minimum | average |
| delta | 86.6 | 100. | 93.3 | 2.3 | 2 | 2.1 |
| Y (a) | 57.7 | 100. | 78.8 | 3.46 | 2 | 2.54 |
| Y (b) | 0 | 100 | 50 | infinity | 2 | 4 |
| Y (c) | 0 | 57.7 | 28.8 | " | 3.46 | 7 |

Although the above stresses are relatively small and on that account probably never immediate causes of breakdown, nevertheless it should be borne in mind that stresses of higher frequency are superimposed upon these. It therefore follows that with the transformer connection possessing the smallest average insulation stress at fundamental frequency, or conversely, that

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connection which possesses the maximum insulation safety factor (when fundamental stresses only are considered), a greater margin is available for withstanding stresses at higher frequencies. These margins, which are obtained by subtracting the insulation stresses given in Tables I and II from the transformer test voltage (200 per cent of normal voltage), are given in Tables III and IV.

TABLE III

INSULATION MARGINS FOR NORMAL OPERATIONS, IN PER CENT OF LINE VOLTAGE.

| | maximum | minimum |
|---|---|---|
| delta | 171 per cent | 142.3 per cent |
| Y | 200 | 142.3 |

TABLE IV

INSULATION MARGINS WITH ONE TERMINAL GROUNDED, IN PER CENT OF LINE VOLTAGE.

| | maximum | minimum |
|---|---|---|
| delta | 113 per cent | 100 per cent |
| Y (a) | 142 | 100 |
| Y (b) | 200 | 100 |
| Y (c) | 200 | 142 |

These tables, however, only roughly indicate that the Y connections, particularly in the case represented by curve *c* of Fig. 1, are capable of withstanding greater stresses at higher frequencies than the delta connection; it would be a true indication provided the insulation is only capable of withstanding twice the line voltage. The table should therefore have been worked out in terms of the actual strength of the insulation instead of the test voltage for which it was designed.

*Line Grounds on Isolated Systems.* In an isolated system, when a solid ground occurs on the line, the grounded wire is reduced to zero potential and the potentials of the other lines are raised to line potential above ground. If a ground occurs on the line, a considerable distance from the transformers, the charging current flowing through the reactance of the line will cause the potential of the grounded line at the transformer to be somewhat above zero, and since the induced voltage of the transformer will also be somewhat greater than its normal value on account of the reactance drop caused by the charging current (particularly when the transformer possesses high inherent reactance), the free line is raised to a fair percentage above its normal potential above ground. This effect is also somewhat larger than one

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would ordinarily assume, on account of the fact that the electrostatic capacity of a transmission line having one of its lines solidly grounded is in the majority of cases considerably greater than when the lines are thoroughly insulated. However, none of these effects are very large, and in general the result of a dead

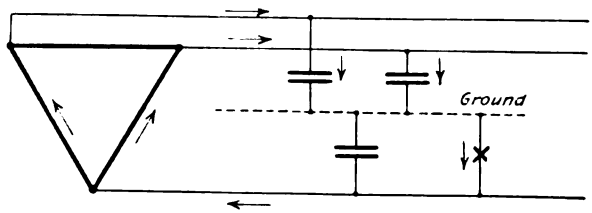


FIG. 2

ground on an isolated system is to bring the other two wires to a potential somewhat greater than normal above ground. The insulation safety factor has thereby been reduced to a value slightly less than two. It is evident that the values of insulation stresses and safety factors given in Tables I and II and the curves in Fig. 1, are not quite correct when transformers are connected

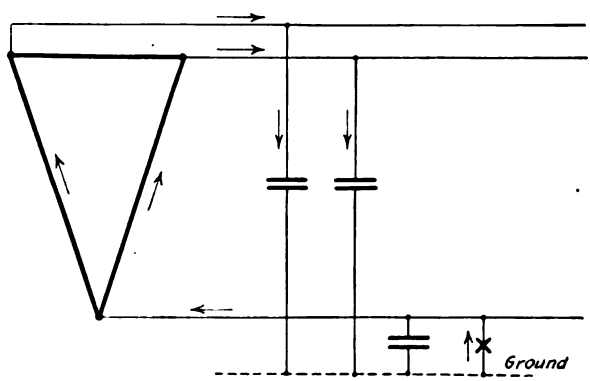


FIG. 3

to transmission lines of considerable electrostatic capacity. It is possible to operate an isolated system with one of its lines solidly grounded without serious risk, and there have been cases of high-voltage, long-distance transmission lines operating in this manner for several hours with a solidly grounded or even a broken line.

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But when the ground occurring on the line is not a dead ground, an arc results between line and ground which, on account of the fact that it is in series with the electrostatic capacity of the transmission line (see Fig. 2), generally results in an unstable arc or an arcing ground.

If the arc, however, is stable, the potential of the arc and line is reduced to ground and may have its potential reversed if higher harmonics introduced by the arc happen to be in resonance with the natural period of the grounded system. This is shown diagrammatically in Fig. 3.

Such conclusions are corroborated by the results obtained in the experiments made by Dr. E. J. Berg, and reported in an Institute paper[2] in June, 1908, entitled *Tests with Arcing Grounds and Connections*.

*Grounds on a System Having Neutral Grounded.* A ground on a system having a neutral grounded results in a short

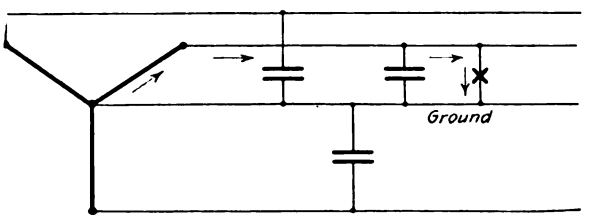


FIG. 4

circuit, and a dynamic current flows, the value of which depends upon the combined impedance of the circuit through ground and impedance of the transmission line and connected apparatus through which the short circuit flows. (See Fig. 4). This results in an impedance drop throughout the circuit and a consequent lowering of the voltage. The resultant arc is in series with the reactance of the transmission line, and since reactance tends to stabilize an arc, the likelihood of an arcing ground resulting is therefore much more remote than in the case of the isolated system.

In general, with the grounded Y system, resonance on account of the electrostatic capacity of the line is not likely, since the line capacity is not in series with line grounds. There is one particular case, however, when resonance may be produced. For example, in a delta-Y system with grounded neutral, suppose

2. TRANSACTIONS A. I. E. E., 1908, XXVII, Part I, page 741.

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one phase on the delta side is burned open, resulting in open delta excitation. The high-voltage side of the burned-out phase then constitutes a reactance in series with electrostatic capacity of the transmission line and excited by the voltages from the other two phases. If the charging current of the transmission line is equal to the magnetizing current of the transformer, resonance is established at fundamental frequency. However, the increase in voltage is limited by the saturation of the transformer; for example, assuming that the normal flux density of the transformer is 80,000 lines per sq. in. (6.452 sq. cm.), it follows that more than a 50 per cent increase in voltage can hardly be expected. The resulting stresses on the insulation are therefore less than those reached in isolated systems when grounds occur on the line.

If the voltage impressed on the low-voltage side contains a

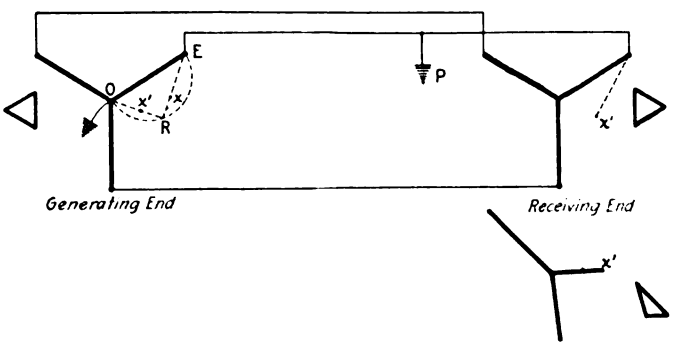


FIG. 5

prominent fifth harmonic, there is a probability of establishing resonance at five times normal frequency, and dangerous voltages built up thereby. However, the likelihood of obtaining resonant conditions at five times normal frequency is not very great, and moreover the fifth harmonic in impressed voltage is generally small. Also the importance of this consideration is small on account of the fact that it can only take place when one delta bank is connected to the transmission line and when one phase of the low-voltage delta becomes open-circuited.

The effect upon the distribution of the voltage, of a line ground on a grounded Y system, is shown diagrammatically in Fig. 5. The portion consumed by line resistance and reactance brings the potential of $P$ to some point $X'$ and the potential $OX'$ is consumed in overcoming the resistance of the current path from the line ground $P$ to neutral $O$.

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The worst short circuit occurs when a dead ground happens on the line near transformer $A$, which causes a collapse of the short-circuited phase throughout the system, and a short-circuit current only limited by transformer reactance.

*Resistance in Neutral.* To reduce the value of this short-circuit current, resistances are often inserted between the neutral point and ground.

A resistance inserted in the neutral causes the neutral $o$ to shift with respect to ground when a ground occurs on the line, or relatively speaking, the ground will shift along the line $OX_1$. If resistances of ground is small compared to resistance at neutral the ground potential in Fig. 5 is $X'$. A dead ground on the line near the transformers causes the neutral to shift a value equal to $\frac{rE}{r+jx}$, where $r$ equals resistance of neutral and $x$ equals reactance of transformer. It is evident that an increase in potential stress on the remaining phases results.

Assume a transformer with six per cent reactance, and resistance of neutral which will limit the current resulting from a dead ground to three times normal (that is, the resistances and reactances together are equivalent to an impedance of 33 per cent). The reactance of neutral must, therefore, be $\sqrt{(33)^2 - (6)^2} = 32.5$ per cent, and the neutral shift will be equal to $3 \times 32.5 = 97$ per cent. *Evidently any resistance inserted in the neutral, if it is to limit currents to values appreciably less than those obtained when the neutral is dead grounded, must be capable of withstanding practically normal phase potential.* More-over, the purpose of grounding the neutral is destroyed, for a neutral shift of 75 per cent or more of the phase voltage means that the free lines have been raised to practically full line potential above ground.

A neutral will therefore remain stable only when the $IR$ drop produced across the neutral resistance by the short-circuit current is small compared with the line voltage. Practically all the voltage must be consumed by the resistance of the ground and resistance of neutral in series. From this we can conclude that *a neutral with resistance will hold the neutral fairly steady and prevent undue rises in potential, provided the line grounds do not occur with resistance* (including line resistance to point of ground) *less than ten times the resistance in the neutral.*

The ratings of the resistance inserted in the neutral for various limiting values of short-circuit current are given in Table V. These are worked out on the basis of transformer reactance

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equal to six per cent, resistance one per cent, and on the assumption that the short-circuit current is limited only by the resistance in the neutral and the impedance of the transformers.

TABLE V

| Short-circuit current | Volts across neutral in per cent of transformer normal voltage | Rating of kv-a. resistance in per cent of normal kv-a. of one phase |
|---|---|---|
| 16.4 times normal | 0 | 0 |
| 12 " " | 57 | 644 |
| 10 " " | 70 | 700 |
| 5 " " | 90 | 450 |
| 3 " " | 94 | 280 |
| 2 " " | 98 | 196 |
| 1 " " | 100 | 100 |
| 0.5 " " | 100 | 50 |

The size of the resistance will also depend upon the length of time short circuit is maintained. For example, if the system is protected by relays which disconnect the apparatus in two minutes, the resistance must be designed to dissipate the power given in the table for this period of time.

*Grounding the Neutral at Receiving End.* In the preceding discussion the neutral at the generating station was in every case considered grounded. However, when the neutral of the step-down transformers at the far end of the transmission line is grounded, and the neutral at the generating station isolated, a different condition exists. In this case, when one line near the step-down transformers becomes grounded, one phase is short-circuited thereby, and current flows as indicated by the arrows in Fig. 6. If the step-down transformers are small compared with the kilovolt-ampere capacity of the system to which they are connected, the line voltage is not appreciably affected by this short circuit, although the grounded line assumes ground potential. Line potential is therefore impressed across two phases, as indicated in *a* of Fig. 6, and the ungrounded lines assume a potential of practically line voltage above ground. The currents flowing are single-phase and produce in each phase a reactance drop equal to *ab*, that is, phase voltage.

If, on the other hand, the step-down transformers have a kilovolt-ampere rating comparable with the rating of the transformers at the generating station, the resulting short-circuit currents are severe enough to reduce the line potential at the step-down transformers very materially. On that account

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they are not as liable to an increase in induced potentials and potential stresses from winding to ground.

Complete protection, however, is not given in this case to the step-up transformers, for if a ground occurs near the generating station, the short-circuit currents must flow through the ground between the generating station and receiving end, in which case the voltage drop on the ground and in lines may be sufficient to limit the short-circuit currents, and therefore decrease the reactance drop within the transformers. Under this condition, the terminals of the step-up transformers will assume a potential above ground equal to line voltage.

*Auto-Transformers.* Wherever it is desired to interconnect two high-voltage systems of not very great voltage difference,

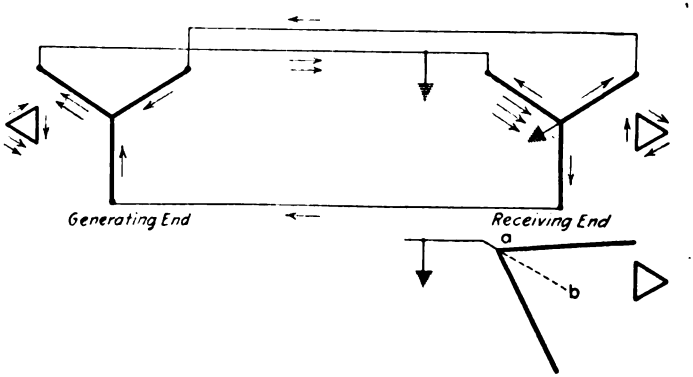


FIG. 6

as, for example, 100,000 volts and 60,000 volts, the use of Y-connected auto-transformers is cheaper than transformers, because a large saving is effected due to the fact that the rating is only a fraction of the power which the auto-transformer can transmit from one system to the other. Since reduction in rating is only material when the connection is Y, a delta-connected auto-transformer is seldom used. But when the transformation ratio is three or more, the saving in the use of auto-transformers instead of transformers is too small to outweigh the disadvantages which their use entails.

As auto-transformers are cheaper from the standpoint of first cost, it is of interest to investigate potential stresses at normal or fundamental frequency resulting from abnormal conditions, as line grounds, etc., in order to determine their

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reliability and therefore their eventual cost. These insulation stresses depend upon whether the system is isolated or grounded Y, and whether the neutral of the auto-transformer is grounded. There are four cases:

CASE I. SYSTEM ISOLATED, AUTO-TRANSFORMER NEUTRAL UNGROUNDED (SEE FIG. 7)

(a) A triple-frequency e.m.f. exists from line to neutral, increasing the induced potential stress from 20 to 50 per cent, depending upon the flux density in the iron. The insulation stress from winding to core is increased at the neutral, but not at the line ends of the winding. The presence of the triple-frequency voltage, therefore, is not serious, for although the average potential stress on the insulation is increased, the maximum stress is not affected.

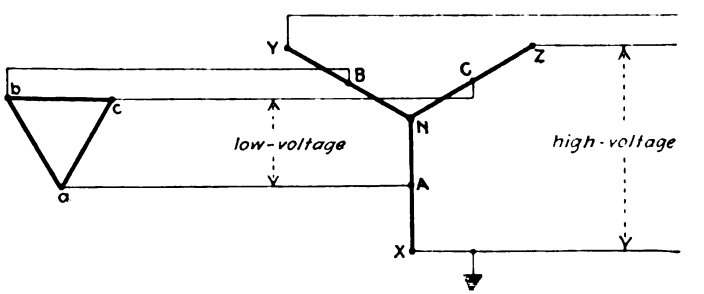


FIG. 7—SYSTEM ISOLATED, AUTO-TRANSFORMER NEUTRAL UNGROUNDED

(b) A ground at $X$ (Fig. 7) places the low-voltage lines $B$ and $C$ at a potential above ground approximately equal to 0.58 high-voltage + 0.42 low-voltage.

Thus, if the auto-transformer steps up from 60,000 volts to 100,000 volts, a solid ground existing on the high-voltage line raises the potential of the low-voltage line to 81,000 volts above ground.

CASE II. SYSTEM ISOLATED, AUTO-TRANSFORMER NEUTRAL GROUNDED (FIG. 8)

(a) The triple-frequency e.m.f. which is present as in Case I, is now exerted across the line insulation to ground. This is particularly dangerous if the auto-transformer is connected to systems having considerable electrostatic capacity. Electrostatic capacity between lines and ground causes a charging

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current in which the third harmonic is prominent, which reacts on the triple-frequency e.m.f., intensifying it. Potential peaks equal to three times normal can easily be obtained in this way at ordinary densities, although at very low densities and at saturation densities, the danger is less. The charging current necessary to produce these voltages is not large.

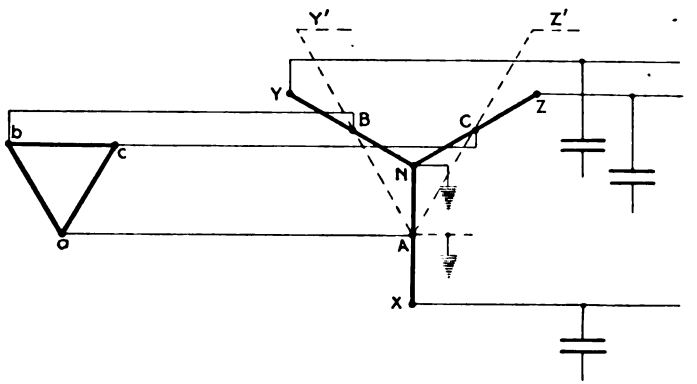


FIG. 8—SYSTEM ISOLATED, AUTO-TRANSFORMER NEUTRAL GROUNDED.

(b) A ground at $A$ causes $NA$ to collapse, $NA$ and $X$ are reduced to ground potential and the remaining phases receive open delta excitation at 1.73 normal flux density. This is shown by the dotted lines in Fig. 3. $B$ and $C$ are placed at low-voltage potential above ground.

(c) A ground at $X$ produces the same result as a ground at $A$.

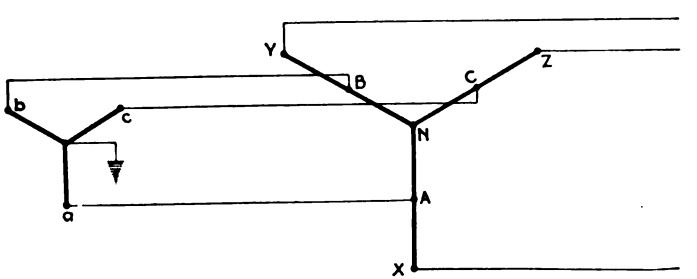


FIG. 9—SYSTEM GROUNDED, AUTO-TRANSFORMER NEUTRAL UNGROUNDED

CASE III. SYSTEM NEUTRAL GROUNDED, AUTO-TRANSFORMER NEUTRAL ISOLATED (SEE FIGS. 9 AND 10)

(a) Triple-frequency voltage present as in Case I. Since the neutral is isolated, there is no danger of the triple-frequency voltage being intensified.

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(b) A ground at $A$ short-circuits one phase of the low-voltage system.

(c) A ground at $X$ results in distortion of and increase in induced voltage in the auto-transformers, as shown in Fig. 5. The low-voltage system does not receive an abnormal voltage or abnormal insulation stress.

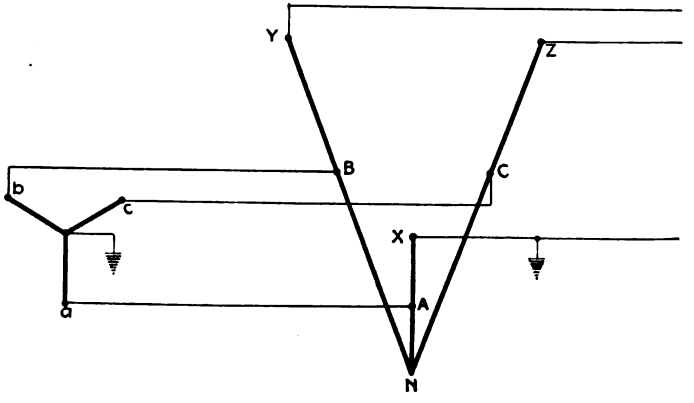


FIG. 10—SYSTEM GROUNDED, AUTO-TRANSFORMER UNGROUNDED, SHOWING EFFECT OF DEAD GROUND OCCURRING ON LINE

CASE IV. SYSTEM NEUTRAL GROUNDED, AUTO-TRANSFORMER NEUTRAL GROUNDED (SEE FIG. 11)

(a) Triple-frequency e.m.f. is much reduced because triple-frequency currents can flow through ground connections. The

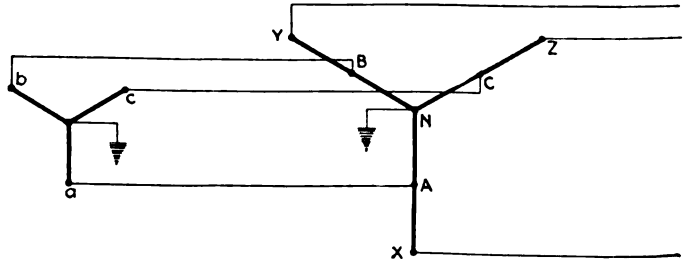


FIG. 11—SYSTEM GROUNDED, AUTO-TRANSFORMER NEUTRAL GROUNDED.

reduction in triple-frequency e.m.f. depends somewhat upon the resistance of the ground circuit.

(b) A ground at $A$ short-circuits one phase of the low-voltage circuit.

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(c) A ground at $X$ short-circuits one phase of the auto-transformer and one phase of the low-voltage circuit through the auto-transformer reactance. The potential of $B$ and $C$ cannot rise above normal values.

In the above cases, single-phase auto-transformers were assumed, although the same results are obtained in three-phase shell type units. In the three-phase core type transformers, the triple-frequency e.m.f. is reduced to negligible proportions on account of the interlinked magnetic circuit. Moreover, in the case of a grounded neutral, when a ground occurs on the line, the interlinked magnetic circuit resists the collapse of one phase, by causing heavy currents to flow in all three phases. The value of this current depends upon the resistance of the ground, a dead ground in the majority of cases causing currents comparable to short-circuit currents.

If the neutral of the system is grounded through a resistance to limit short-circuit currents, excessive currents are prevented when a ground occurs on the line. However, in that case the neutral will remain stable only for high-resistance line grounds. If a dead ground occurs on the line, full phase voltage is impressed across the neutral resistance and potential stresses will exist similar to those occurring in isolated delta systems. In general, it may be said that the grounded neutral, with a resistance to limit the current flow, acts like a solidly grounded system as long as grounds of high resistance only occur on the line. When a dead ground occurs, the resulting potential stresses will be practically the same as if the system were operating ungrounded.

It should be borne in mind that the conditions in the majority of practical cases considerably depart from those cited here. For example, in the case shown by Fig. 7, the normal flux density may be so high that the magnetizing current required for 73 per cent increase in voltage will be so great as to cause a line reactance drop sufficient to reduce considerably the voltages applied to the transformers. However, the diagram applies rigidly to all cases where the normal flux density is made low enough so that, when a ground occurs, the cores will not be super-saturated. Similarly, the conditions shown by Fig. 5 will not occur in practise on account of the excessive magnetizing currents resulting.

It is evident from the analysis of the four cases given above, that high-voltage auto-transformers should not be used without

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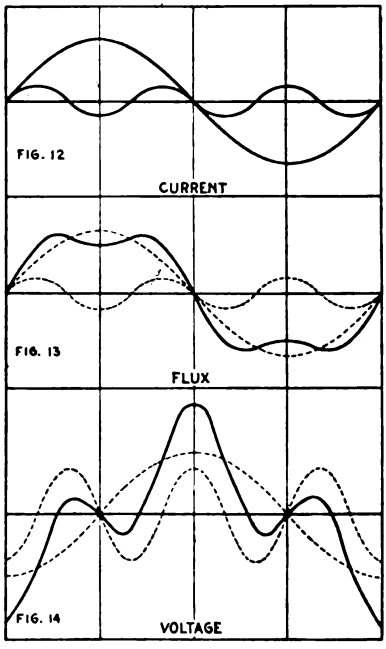
solidly grounding the neutrals. Grounding the neutral necessitates the elimination of the triple-frequency e.m.f., which may be done either by using the three-phase core type structure or by having a Y-delta transformer with ground neutral connected to the same system. The latter method, is, however, questionable because the safety of the auto-transformer then depends upon proper operation of another piece of apparatus.

If such precautions are taken, auto-transformers should operate successfully, although they still possess the objection that the high-voltage and low-voltage systems are rigidly connected together by means of an electrical conductor, whereas a transformer connects the systems in a more flexible manner, *i.e.*, magnetically. Due to this, a disturbance occurring on one line is likely to be felt on the other, when auto-transformers are used. With tie-in transformers, operating on isolated systems, it is possible for grounds to occur on line without disturbing the operation or increasing the stresses on the other lines.




FIGS. 12, 13, 14—CURRENT, FLUX AND VOLTAGE RELATIONS IN Y-CONNECTED AUTO-TRANSFORMERS

## THE THIRD HARMONIC IN THE Y CONNECTION

Due to the fact that the permeability of iron decreases as the flux density increases, the wave shape of magnetizing current in a transformer is different from the wave shape of the electromotive force. When the impressed electromotive force is a sine wave, the magnetizing current shows a peak, which, when analyzed, resolves itself into a prominent third harmonic and higher harmonics of lesser values.

In the Y connection, third harmonic currents and currents having frequencies multiples of the third cannot flow on account of the fact that these currents in the three phases would be in

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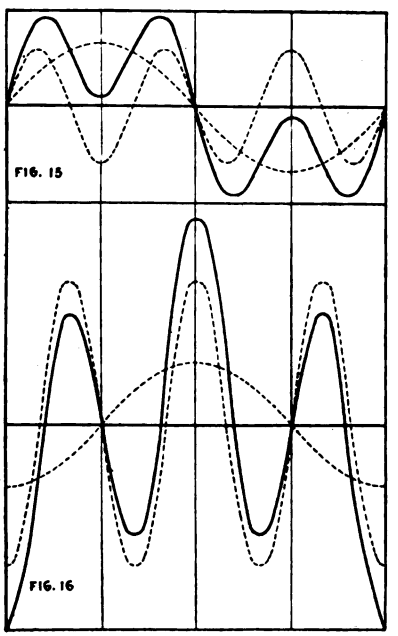
phase with each other, and to permit them to flow, a circuit must be provided at the neutral.

Owing to the fact that the triple harmonic current necessary for sinusoidal excitation cannot flow in Y-connected transformers the resulting flux wave takes a flattened form, which, when analyzed, resolves itself into the fundamental and a triple harmonic. The flux wave under this condition is shown in Fig. 13, and the corresponding voltages induced from line to neutral are given in Fig. 14. For average operating densities in transformers, the triple harmonic voltage is approximately 60 per cent of fundamental voltage.




FIGS. 15, 16—ANALYSIS OF THIRD HARMONIC INTENSIFICATION IN Y AUTO-TRANSFORMERS

When the neutral of the auto-transformer is grounded, the triple harmonic together with the fundamental is impressed between line and ground across the capacity of the connected transmission line. A triple-frequency charging current flows into the line and through the auto-transformer windings. The phase angle of this current with reference to the fundamental magnetizing current is shown in Fig. 12. This triple-frequency current constitutes an additional magnetizing current in the auto-transformer, and a comparison with Fig. 13 shows that it is in phase with the triple-frequency flux which was produced by the original sine wave magnetizing current. Therefore the triple-frequency current acts to increase the triple-frequency flux and a corresponding intensification of triple voltage ensues. The increased triple harmonic voltage results in a greater triple current, which causes a further increase in flux. This intensification is only limited by the saturation of the transformer. Figs. 15 and 16 show flux and voltage waves in which the third harmonic has reached its maximum value. It is evident that under such conditions of operation the core loss of the transformers will

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be about three times normal and the insulation stress about four times normal.

## Conclusions

The following are the more important conclusions which may be drawn from this paper:

First: Isolated systems are subject to greater insulation stresses than grounded systems.

Second: In grounded systems, the average insulation factor of safety is greater than in isolated systems under similar conditions of operation.

Third: In isolated systems, the stresses at lower frequencies under certain conditions, may reach values sufficiently high to injure or destroy the transformer and other apparatus connected to the system.

Fourth: In an isolated system, a ground on the line is more likely to result in an arcing ground or intermittent arcs than in a grounded system.

Fifth: A ground on the line in a solidly grounded system, reduces the potential of the system with respect to ground, whereas in the isolated system, a ground on the line increases the potential of the system with respect to ground.

Sixth: A resistance inserted between neutral and ground to limit the value of short-circuit current increases thereby the insulation stresses resulting from line grounds.

Seventh: If it is desired to limit the value of potential at fundamental frequency above ground of any part of the system to 57 per cent of line potential, it is necessary to solidly ground the neutrals at both receiving and generating ends of transmission line.

Eighth: If receiving transformers of relatively small kilovolt-ampere capacity are connected with grounded neutral to an otherwise isolated system, they are liable to severe short circuits, and the grounded neutral only partially protects the system from potential rises.

Ninth: In Y-connected auto-transformers, it is dangerous to operate with isolated neutral except when the ratio of transformation is very small.

Tenth: In Y-connected auto-transformers, it is dangerous to operate with isolated neutral except when the entire system is isolated.

Eleventh: In Y-connected auto-transformers, it is dangerous to operate with grounded neutral unless the triple harmonic voltage between line and neutral is eliminated or kept negligibly small.

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# A STUDY OF SOME THREE-PHASE SYSTEMS

BY CHARLES FORTESCUE

ABSTRACT OF PAPER

The star-star, delta-delta, delta-star and star-delta connections are taken up in order and their individual peculiarities and characteristics, precautions that must be taken in operation to avoid trouble and where and when the system may be grounded with best results, are discussed.

The question of delta-delta vs. delta-star is considered:

(1) For moderate voltages the delta-delta system has the advantage on account of its greater flexibility.

(2) For high voltages the delta-star connection is preferable, chiefly on account of its greater strength and lower cost. There is a probability that a delta-star bank of transformers will cause less disturbance in switching than one that is delta-delta connected.

(3) There are much greater possibilities of development in transformers designed for delta-star connection than for any other.

(4) Past and present practise upholds the use of the delta-star connection in preference to the delta-delta for high-voltage transmission.

IT IS proposed in this paper to study several common methods of connecting transformers for use on polyphase systems with the view of displaying the advantages and disadvantages of each, showing under what conditions they may be used to the best advantage.

## STAR-STAR CONNECTIONS

It is well known that on account of the shape of the hysteresis loop of transformer iron, the m.m.f. required to produce a sine wave of induction in a magnetic circuit of uniform cross-section made of iron will not be of simple sine wave form, but will include a third harmonic wave; and vice versa, if the third harmonic be absent from the m.m.f. it will appear in the wave form of the induction. In the primary of a star connected group of transformers the sum of the three currents flowing towards the neutral point must be zero, consequently, the third harmonics of the magnetizing currents in each phase, being of the same phase, are suppressed and a third harmonic appears in the e.m.f. between the neutral and the supply mains.

The presence of the third harmonic in the e.m.f. between the



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neutral and mains of the primary circuit does not materially affect the e.m.f. between lines in the secondary circuit, but a load cannot be taken off between the neutral point and lines because this e.m.f. is unstable, that is to say, the neutral point will shift. The reason for this is evident and needs no explanation. If the neutral point of the secondary circuit be grounded the secondary line terminals will have a third harmonic pulsation to ground which may cause serious disturbances in neighboring telephone circuits.

In single-phase transformers and three-phase shell-type transformers this third harmonic component of the wave form may be entirely eliminated by using an interconnected star primary or secondary winding; and if care be taken to properly interlace the windings, the neutral point will be stable and a load may be taken off the secondary circuit between the neutral and lines.

If the neutral point of the primary winding be connected to the neutral point of the generator the secondary neutral point will be stable, and loads may be supplied between the neutral point and the lines; but, since the generator itself may have a third-harmonic component in the e.m.f. between neutral and terminals it is not advisable to ground the neutral point of the secondary winding. If, however, the secondary winding be in interconnected star, the neutral point may be grounded without causing trouble.

The reason why the interconnected star primary eliminates the third harmonic component is that there is an interchange of third harmonic m.m.f. due to the primary and secondary interactions of the interconnected windings.

In three-phase transformers of the form of construction known as core-type, that is to say, transformers with interlinked magnetic circuits, this same interchange of m.m.f. takes place between the phases, so that, each phase has part of the required m.m.f. supplied from the other two phases during a portion of the cycle. The sum of the three magnetic fluxes must be zero and therefore, the sum of the three induced e.m.fs. must also be zero and thus the neutral point is the centroid of the primary voltage triangle. In such transformers due to the above mentioned interchange of third-harmonic m.m.f. there exists a third-harmonic leakage field in the air external to the coils. The neutral point will be symmetrical, even with wide differences in the permeability of the cores, the required m.m.fs. for the three cores

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being supplied on the proper relation by the three primary windings. The magnetizing currents in three-phase transformers of this type which are unsymmetrical have third-harmonic components, which are in three-phase relation and produce unlike waves in the three phases.

If a load be taken off the secondary of a three-phase transformer of the type under discussion, a leakage field is set up in the coil spaces between the loaded phase and the other two which is usually large. The regulation of such transformers for loads between the neutral and lines is not usually good. The condition is similar to the effect of loading one side of a single-phase core-type transformer connected for three-phase distribution which had not been designed with cross-connected secondary windings. Interconnection of the primary or secondary windings is one remedy for this trouble.

If a three-phase transformer or group of single-phase transformers be intended to operate with the neutral of the primary connected to the neutral of the generator, the primary winding should not be interconnected, because thereby the impedance to the flow of the third-harmonic current set up by the third-harmonic component in the generator e.m.f. wave between neutral and terminals is rendered very small and these currents may be large enough to cause undue heating.

In the straight star-connection with single-phase transformers, the voltage stress per turn on the windings is quite high on account of the excessive peaking of the e.m.f. between neutral and lines. The core loss of the transformers is usually lower than for a sine wave e.m.f. even though the effective value of the neutral to line e.m.f. is more than 57 per cent of the e.m.f. between lines. Formerly it was considered a grave disadvantage of this connection that a short circuited unit would cause 73 per cent increase in stress on the other two. It is not probable now that such a condition could exist without tripping the breakers, since this increase in voltage with the steel now used in transformers would result in a magnetizing current having an effective value several times the full load value of current.

The advantage of the star-star connection of single-phase transformers is in its simplicity and low cost. It is not suitable for four-wire three-phase distribution, nor should it be operated with the neutral grounded. The transformers are subjected to an undue stress between layers and between coils on account of the distorted e.m.f. between neutral and lines.

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If the neutral of the primary be connected to the neutral of a generator which has no third-harmonic component the connection may be used for four-wire three-phase transmission with or without the neutral point grounded.

If, on account of the desirability of grounding the neutral point it is found necessary to interconnect the windings, the advantage of simplicity and low cost is lost, to a great extent.

Three-phase transformers star-star connected may be used with or without the neutral grounded, for three-phase three-wire transmission. Light loads may also be taken off between neutral and line. Interconnecting the low-tension winding does not involve much trouble, but it is simpler to connect this winding delta, which produces the same result in a simpler manner.

Star-star connected three-phase transformers have the same advantage as single-phase transformers connected in the same manner, and the stress to which the insulation is subjected may be reduced to a smaller value for a given voltage between terminals than with any other connection; this advantage, however, is of little consequence when the line e.m.f. is low. They have the additional advantage that the e.m.fs. between neutral and lines do not have a third harmonic.

### Delta-Delta Connection

This connection is the most widely used of all three-phase connections, and is recommended for moderately high voltages on account of its extreme flexibility.

The third harmonic and its multiples are eliminated in the terminal e.m.fs. of a symmetrical star-connected generator, and if the three delta connected transformers are alike in design and magnetic characteristics they will be absent in the secondary e.m.fs. Differences in characteristics of the transformers are corrected in this connection by interchange of m.m.f. through the secondary windings. A marked dissymmetry in the bank of transformers may cause a third-harmonic component in three-phase relation to appear in the secondary e.m.f.s between lines; but the usual third-harmonic distortion characteristic of the secondary e.m.f. of single-phase transformers is not present in the e.m.f. between phases, due to the fact that the delta-delta connection affords a low impedance path to the flow of current set up by such a component, thereby automatically eliminating it. In three-phase transformers of the form known as core-type, the interlinking magnetic circuits of the three phases somewhat

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modify the interactions between the three phases but the differences in action from single-phase transformers connected in delta are trifling.

The chief advantage of the delta-connected group of single-phase transformers lies in its flexibility. If one of the transformers in a group fails the other two are able to supply power at a diminished rating, the only change being the cutting out of the defective transformer, which may be done without interference with the operation of the other two.

The stresses to which the insulation is subjected are higher than in the star connection, and there is no means of grounding the neutral except through the intermediary of an interconnected star group of single-phase auto-transformers or a three-phase auto-transformer, or some such device, provided with a star connection.

### Star-Delta and Delta-Star Connection

These methods of connecting transformers have been the subject of a good deal of controversy, and have suffered through misapplication. It was pointed out that in the star-star connection it was necessary to interconnect the primary winding to eliminate the distorting third harmonic and to obtain a stable neutral point; this is effected in the delta-star connection at a minimum cost, and with a maximum degree of stability of the neutral point. It is in reality a more direct transformation than the delta-delta connection; since there can be no interchange of m.m.f. between phases, the secondary neutral to line e.m.f. is the same as that obtained with single-phase transformation and may contain a trace of third harmonic as in single-phase transformer due to the reactive drop of the exciting current.

The three-phase core-type transformer with delta-star connection has a stable neutral point and also on account of the interlinked magnetic circuits the secondary neutral to line e.m.f. is absolutely free from third harmonic. The three-phase shell-type does not differ materially from three single-phase transformers.

The star-delta connection has some very interesting peculiarities, lack of understanding of which has led to its improper use, resulting in troubles which have been considered as the fault of the connection, rather than of the individuals who misapplied it. In this connection the sum of the secondary induced e.m.fs. must be zero on account of the delta-connected secondary, consequently the neutral point of the primary star connection

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must be the centroid of the primary e.m.f. triangle except for the slight distortions caused by the drop due to the exciting currents in the windings. It has already been pointed out that a third-harmonic component is required in the m.m.f. wave to produce a sine wave of induction. If, therefore, the primary is star connected from what source is this third harmonic m.m.f. supplied? The answer is that it is supplied to each phase as required by the other two through the secondary delta-connected winding, so that there exists a circulating third-harmonic magnetizing current in the delta of transformers connected in this manner, which is equal in magnitude and time phase to the equivalent component in the normal single-phase secondary exciting current of the transformers. The effect of differences in the magnetic characteristics of transformers so connected is to cause slight dissymetry in the secondary e.m.f. waves between lines, which is due to third-harmonic components in three-phase relation which appear in these e.m.fs.

If the neutral of a star-delta connected bank of transformers be connected to that of the generator supplying the transformer the result will be a short-circuit so far as the third-harmonic component of the generator between neutral and terminals is concerned, the flow of third harmonic current being limited only by the impedance of the transformers, and very serious heating may result both to the generator and to the transformer. Since the neutral of the transformer is stable there is no necessity for connecting it to that of the generator and if it is desired to ground the primary system this may be done most advantageously by grounding the neutral point of the bank of transformers.

The delta-star connected three-phase transformer, or bank of transformers, is suitable for three-phase transmission and distribution with both three and four wires. A load taken off between neutral and line will cause the neutral to shift only an amount equal to the impedance drop of the transformer supplying the loaded phase. In four-wire three-phase systems, where the e.m.f. is stepped up through delta-star transformers, and three-phase power is supplied through star-delta step-down transformers the latter, if their neutral be connected to the neutral, serve as balancers for loads taken off between neutral wires and lines. Fig. 1 will suffice to explain this action of the star-delta connected bank transformers. A small bank of star-delta connected transformers in the neighborhood of a heavy unbalanced load taken off between neutral and lines at the end of a long feeder,

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is, on account of this characteristic, liable to be overloaded if its neutral be connected to the neutral wire.

An interesting peculiarity of these connections is that when the wave form of applied e.m.f. is not a sine wave, a peaking harmonic in the e.m.f. across the lines will produce a flatting harmonic in the e.m.f. between neutral and lines, and vice versa, although the effective values will be in the ratio of 1 to $\sqrt{3}$, as for a sine wave; as a consequence the core loss of a three-phase star-delta connected transformer may have different values when measured on the star side and delta side, when the form factor of the impressed wave differs from that of a sine wave.

The star-delta and delta-star connection has all the advantages of the star-star connections without their grave disadvantages; as pointed out before, when the e.m.f. is low there is no

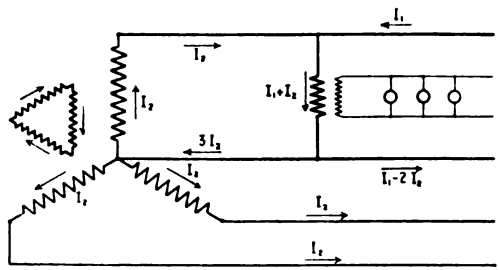


FIG. 1—ILLUSTRATING THE REGULATING EFFECT OF A STAR-DELTA CONNECTED GROUP OF TRANSFORMERS ON A THREE-PHASE FOUR-WIRE SYSTEM.

inherent advantage in the star connection, actually there may be decided disadvantages. There is no advantage in supplying a single-phase load from the neutral point of a generator, on the contrary the single-phase output of a three-phase generator is greatest when the power is supplied from two terminals. The delta-star connection permits of this and therefore increases the unbalanced capacity of the whole system. Consequently, even should it be possible to entirely eliminate the third harmonic from the e.m.f. wave between the neutral and terminals of a generator, the star-star connection is hopelessly out of the running when it has to compete with the delta-star connection. In three-phase transformers the delta-star connection is the most economical way of obtaining good regulation between neutral wire and lines in a three-phase four-wire system.

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## Discussion of Delta-Delta and Delta-Star Systems

In the following part of this paper the discussion will be confined to the last two systems of three-phase connections; the proper field for each will be pointed out and the reason given for the selection.

For three-phase transmission at moderate voltages, say up to 33,000 volts, the advantage lies with the delta-delta connection for single-phase transformers, on account of its greater flexibility and because the failure of one unit in a bank interrupts service for only the short length of time required to cut out the defective unit, operation being continued with the transformers connected in V at a reduced rating.

For three-phase four-wire distribution the delta-star and star-delta connected transformers are most suitable. It may not be out of place here to sound a note of warning in connection with supplying single-phase service from three-phase sources grounded or ungrounded. In a single-phase transformer connected to a three-phase system, the secondary winding has a potential determined by the mean-potential of its primary winding and the relative capacity between primary and secondary and between secondary and ground. An ungrounded secondary winding which is disconnected from its wiring may have quite a high potential due to this effect. A preferable way of supplying house lighting from a three-phase line would be by means of a three-phase step-down transformer or bank of single-phase transformers having secondaries connected in star-delta or interlinked six-phase, then if the supply circuit were grounded at the neutral point, the secondary circuit could be operated with safety ungrounded. The practise of running single-phase feeders from a three-phase supply to outlying districts for the purpose of supplying lighting service is bad in so far as when the secondaries are grounded it is liable to interfere with telephone service.

Turning our attention now to three-phase transmission at voltages above 44,000 volts, the problem of insulating begins to assume importance. Figs. 2 and 3 are potential diagrams of delta-delta step-up and step-down transformers and delta-star step-up and star-delta step-down transformers. The point $O$, the centroid of the potential triangle, is at zero potential; the potential of any portion of the winding of any phase is given by the distance of the equivalent point on the potential diagram from the centroid. The e.m.fs. and instantaneous

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potentials are given by the projection of the points $A$ $B$ $C$, $a$ $b$ $c$ on a given line passing through $O$, the triangle $A$ $B$ $C$, it being considered as rotating about $O$ so as to make one complete revolution per cycle. Comparing these two potential diagrams, it will be apparent that the high-tension winding of the delta-star transformer is subject to lower average stress than that of the delta-delta, varying in the first connection from 0 to 57.7 per cent of the line e.m.f. and in the second connection from 28.8 per cent to 57.7 per cent of the line e.m.f.

The tendency of any connection to give trouble during switching will probably depend largely on the amount of potential energy stored in the system under normal operating conditions. The high-tension windings of the transformers

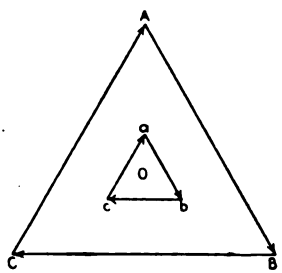


FIG. 2—POTENTIAL DIAGRAM OF DELTA-DELTA CONNECTED BANK OF TRANSFORMERS, NORMAL OPERATION.

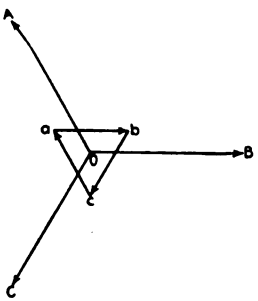


FIG. 3—POTENTIAL DIAGRAM OF DELTA-Y OR Y-DELTA CONNECTED BANK OF TRANSFORMERS, NORMAL OPERATION.

in both connections will have about the same capacity to ground, the tendency being for higher values in the transformers for the delta-delta connection. If $v$ be the effective value of the e.m.f. between lines, the maximum amount of energy stored in the dielectric will be in the case of the delta-delta connection for each transformer $\frac{CV^2}{6}$, and in the case of the delta-star connection it will be $\frac{CV^2}{9}$ for each transformer, the value $C$ being the total capacity of the high-tension winding of each transformer to ground.

It follows in consequence that there will probably be fewer disturbances caused in a transmission system when a star-

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delta bank is switched on and off the circuit than when a delta-delta bank of the same capacity is switched on and off; and therefore the insulation stresses due to switching in the star-delta connection will be correspondingly smaller than in the delta-delta connection.

The same relations hold true for any conditions that may arise in operation which causes the breakers to open, such as a ground on the line, short circuits between phases, etc. In every case the energy stored in the dielectric is less for the star-delta connected group than for the delta-delta connected group.

The dangers arising from switching are caused not so much by the rapid interruption of large currents (for as a matter of fact the rate of diminution at the instant of interruption is not very much greater than if the breaker remained closed), as because, after the current has ceased, the potential energy in the two systems, that is, the disconnected bank of transformers and transmission line, becomes changed into kinetic energy, setting up oscillations in the two systems which produce differences of potential at the disconnecting points sufficient to cause them to arc over. These abrupt changes in condition set up other trains of oscillation which are superimposed on the first, resulting in abnormal stress on the insulation of the transformers.

When the line is disturbed by lightning, the capacity of the transformers will have little to do with the severity of the disturbance. The charge due to a thunder-cloud, when released, sets up waves which on striking the transformers cause a high stress between adjacent turns of the windings, particularly those near the terminals. A large capacity between adjacent turns will tend to reduce the severity of these stresses. In the star high-tension winding the large wide conductors tend to large values of capacity between adjacent turns, which is the condition required for reducing the stresses.

The delta-star grouping has the advantage from an insulation standpoint even if the neutral point is not grounded. With a grounded neutral point the insulation stress is still further reduced, an advantage which cannot be obtained with the delta-delta system without auxiliary star-delta transformers.

The mechanical stresses due to short circuit will be the same for both systems, but delta high-voltage windings are not so well adapted to withstand mechanical shock as the stauncher windings for star connection. It may therefore be stated that,

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with equal mechanical support, the delta high-voltage winding will be mechanically weaker than the corresponding star winding.

Considering the two systems from the point of view of cost, let the cost of winding the coils be considered first of all. The coils used in all power transformers of large capacity are discoidal, sometimes termed pan-cake coils, and consist of spirally wound flat copper ribbon conductors insulated with sleeves or strips of micanite or other insulating material. To enable the workman to produce a servicable coil the conductor must be large enough to hold down the sleeves or layers of insulating materials, otherwise the coil will be "mushy". However carefully a "mushy" coil may be clamped up and treated it can never be as strong mechanically as one more solidly constructed of heavier conductor. More care is therefore involved in winding such coils, in their preparation for treatment and in their handling after treatment, during assembly. The cost per turn per coil is therefore higher, as is also the cost of treatment and handling per coil. There are 73 per cent more turns in a complete delta winding than in a star winding, and an equivalent larger number of coils. The cost of the complete winding will therefore be considerably more for the delta than for the star system.

In assembling, each coil has its own individual insulation; each lead must be tied to its proper position. The coils in a group must be placed in position one by one during assembly and the connections soldered. There are therefore more operations in the assembly of a delta winding than in that of a star winding and the coils have to be handled with more care. The cost of assembly will therefore be higher for the delta-connected than for the star-connected transformers.

Since the conductor to be insulated is smaller in the transformers of the delta group than in those of the star group, the insulation will occupy relatively more space in the former than in the latter, with the result that the dimensions of the transformers for delta connection will be larger and require more active material than those for the star connection.

A transformer designed for delta-star connection is less costly to manufacture than one designed for delta-delta connection. The high-tension wiring of a group of star-connected transformers is simpler than that for one of delta-connected units, which is no inconsiderable advantage with high transmission voltages.

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## Possibilities of Development

The above discussion applies to present standard practise. Considered from the point of view of future development, the advantage is all with the delta-star and star-delta connections. Thus, for example, the worst condition of stress in the transformers arises when one line becomes grounded. Figs. 4 and 5 are the potential diagrams for such a condition. The delta group has a maximum stress varying from line voltage to 87.7 per cent of the line voltage; in the star group the maximum stress varies from line voltage down to 57.7 per cent of the line voltage. If full advantage be taken of this difference the transformer for star connection will be lowered still further in cost.

With the advantage afforded by grounding the system at

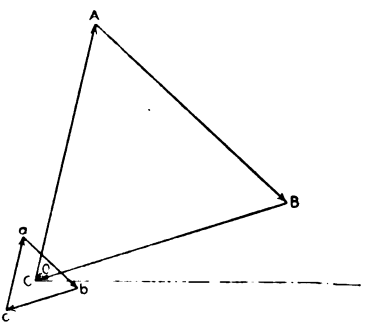


Fig. 4—Potential Diagram of Delta-Delta Connected Bank of Transformers—One Line Grounded.

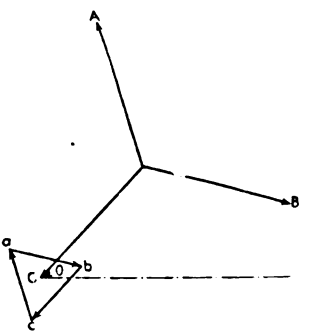


Fig. 5—Potential Diagram of Delta-Y or Y-Delta Connected Bank of Transformers—One Line Grounded.

the neutral point, the star-connected group may be manufactured at a very much lower cost than the delta-connected group.

As improvement in methods of switching will enable the manufacturer to take further advantage of the lower stress to which the star-connected group is subjected under operating conditions, considerable development may therefore be expected in this direction in the future.

## Past and Present Practise

In view of the fact that the largest and most successful power transmissions in America are operated with delta-star step-up star-delta step-down transformers, and that several among them, together with a large number of smaller power companies,

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| NAME | Operating voltage | Frequency (cycles) | Capacity of plant (kilowatts) | Beginning of operation | Step-up Trans. | | | | Step-down Trans. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Phases | Conn. | | Y-grounded direct or through resistance | Conn. | | Dist. of transmission (miles) |
| | | | | | | Low tension | High tension | | Low tension | High tension | |
| Pacific Light & Power Co | 150,000 | 50 | 59,500 | 1913 | 1 | Δ | Y | D. | Δ | Δ | 241 |
| Au Sable Elec. Co | 140,000 | 60 | 9,000 | 1912 | 1 | Δ | Δ | No | Δ | Δ | 235 |
| Southern Sierras Power Co | 140,000 | 60 | 8,750 | | 1 | Δ | Y | R | Δ | Y | 239 |
| Utah Power & Light Co | 130,000 | 60 | 42,000 | 1914 | 1 | Δ | Δ | No | Δ | Δ | 135 |
| Pacific Gas & Electric Co | 125,000 to 110,000 | 60 | 20,000 | 1913 | 1 | Δ | Δ | | Δ | Δ | 110 |
| Tennessee Power Co | 120,000 | 60 | 15,000 | 1914 | 3 | Δ | Δ | No. | Δ | Δ | 140 |
| Connecticut River Transmission Co | 120,000 | 60 | 14,400 | 1914 | 3 | Δ | Y | D. | Δ | Y | 60 |
| Inawashiro Hydro-Electric Power Co | 115,000 | 50 | 42,000 | 1914 | 1 | Δ | Δ | No | Δ | Δ | |
| Grand Rapids Muskegon Power Co | 110,000 | 30 | 9,000 | 1909 | 1 | Δ | Δ | No | Δ | Δ | 35 |
| Ontario-Hydro-Electric Commission | 110,000 | 25 | 106,800 | 1910 | 1 | Δ | Y | R. | Δ | Y | 90 |
| Lauchhammer, A. G | 110,000 | 50 | 15,000 | 1911 | 3 | Y | Y | No | Y | Y | 35 |
| Georgia Ry. & Power Co | 110,000 | 60 | 42,500 | 1912 | 1 | Δ | Y | R. | Δ | Δ | 170 |
| Alabama Interstate Power Co | 110,000 | 60 | 43,200 | 1913 | 1 | Δ | Y | R. | Δ | Y | 50 |
| Mississippi River Power Co | 110,000 | 25 | 12,500 | 1913 | 3 | Δ | Y | R. | Δ | Δ | 140 |
| Mexican Northern Power Co | 110,000 | 60 | 22,890 | 1914 | 1 | Δ | Y | R. | Δ | Y | 47 |
| Lehigh Coal & Nav. Co | 110,000 | 25 | 20,000 | 1914 | 1 | Δ | Y | No | Δ | Δ | 24 |
| Ebro Irrigation & Power Co., Ltd | 110,000 | 50 | 50,000 | 1914 | 1 | Δ | Δ | No | Δ | Δ | 119<br>186 |
| Chile Exploration Co | 110,000 | 50 | 40,000 | | 3 | Y | Y | No | Y | Y | 130 |
| Sierra-San Francisco Power Co | 104,000 | 60 | 34,000 | 1910 | 1 | Δ | Y | D. | Δ | Y | 138 |
| Yadkin River Power Co | 103,900 | 60 | 24,000 | 1912 | 3 | Δ | Y | D. | Δ | Δ | 96 |
| Great Falls Water Power & Townsite Co | 102,000 | 60 | 21,000 | 1910 | 1 | Δ | Δ | No | Δ | Δ | 150 |
| Central Colorado Power Co | 100,000 | 60 | 10,000 | 1909 | 1 | Δ | Δ | No | Δ | Δ | 152 |
| Great Western Power Co | 100,000 | 60 | 60,000 | 1909 | 3 | Δ | Δ | No | Δ | Δ | 154 |
| Southern Power Co | 100,000 | 60 | 75,000 | 1909 | 1 | Δ | Y | R. | Δ | Δ | 195 |
| Shawinigan Water & Power Co | 100,000 | 60 | 24,000 | 1911 | 3 | Δ | Y | R. | Δ | Δ | 87<br>87 |
| Los Angeles Aqueduct | 100,000 | 50 | 22,500 | | 1 | Δ | Y | D. | Δ | Y | 47 |
| Tata Hydroelectric Co | 100,000 | 50 | 32,000 | 1914 | 1 | Δ | Δ | No | Δ | Δ | |
| Appalachian Power Co | 88,000 | 60 | 20,610 | 1912 | 3 | Δ | Δ | No | Δ | Δ | 180 |
| Rio Janiero Tramway, Light & Power Co | 88,000 | 50 | 48,800 | 1913 | 1 | Δ | Δ | No | Δ | Δ | 51 |
| Sao Paulo Elec. Co | 88,000 | 60 | 30,000 | 1914 | 1 | Δ | Δ | No | Y | Δ | 40 |
| Mexican Light & Power Co | 85,000 | 50 | 58,500 | 1910 | 1 | Δ | Y | D. | Δ | Y | 169 |
| Victoria Falls & Transvaal Power Co | 84,000 | 50 | 40,667 | 1913 | 3 | Δ | Y | R. | Y | Δ | 30 |
| Toronto Power Co | 80,000 | 25 | 56,000 | 1914 | 1 | Δ | Δ | No | Δ | Δ | 80 |
| Katsura Gawa Denryoku Kabushiki Kaisha | 77,000 | 50 | 22,400 | 1912 | 1 | Δ | Y | R. | Δ | Y | 48 |
| Southern California Edison Co | 75,000 | 50 | 20,000 | 1907 | 1 | Δ | Y | D. | Δ | Y | 117 |
| Hidro-Electrica Espanola Molinar | 70,000 | 50 | 22,500 | 1910 | 3 | Y | Y | No | Y | Y | 158 |
| Pennsylvania Water & Power Co | 70,000 | 25 | 71,500 | 1910 | 3 | Δ | Y | R. | Y | | 40 |

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have been in operation for a considerable length of time, it seems somewhat superfluous to bring up arguments in support of this method of connecting transformers. Following is a list of power transmissions using transformers star-connected on the high-tension side which have been in operation for a considerable length of time.

| | |
|---|---|
| Ontario Power Company | 66 000 volts. |
| Southern Power Co | 100 000 " |
| Ontario Hydroelectric Power Company | 110 000 " |

Table I gives a list of power companies transmitting at 70,000 volts and above; 22 out of 37 of these use transformers which are star-connected on the high-tension side. One of the most recent is the large power development of the Mississippi River Power Co., the Keokuk development transmitting power at 110,000 volts. Perhaps the most notable of recent power developments is that of the Pacific Light and Power Company, transmitting at 150,000 volts, which employs the delta-star connection.

It will be evident from this table that the advantages of the delta-star connection are recognized by a large number of engineers; but it should be used universally for transmission voltages above 66,000 volts instead of in a little more than 50 per cent of the cases as the table indicates.

## Conclusions

For transmission voltages below 44,000 volts, either transformers with star or delta-connected high-tension windings may be used; the delta connection has a slight advantage due to its greater flexibility. For transmission voltages above 44,000 volts, transformers with star-connected high-tension windings should be used.

This conclusion is upheld by sound reason and also because it has been tried out successfully on some of the largest transmissions in the world, several of which have been operating successfully for a large number of years.

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# HARMONIC VOLTAGES AND CURRENTS IN Y- AND DELTA-CONNECTED TRANSFORMERS

BY R. C. CLINKER

ABSTRACT OF PAPER

The paper reviews the conditions under which triple harmonic voltages and currents are produced in Y-and delta-connected transformers. These voltages are produced by hysteresis in the core. In a single-phase transformer, increase of series resistance tends to suppress the current harmonic and produce the voltage harmonic. In three-phase transformers, a Y connection suppresses the current harmonic and allows the full flux and voltage harmonics to appear. Delta connection provides a closed path for the current harmonic, and suppresses the triple voltage.

A case is cited where a Y-connected auto-transformer was used to step up from 6600 to 12,000 volts at a substation. The neutral was not grounded, and trouble resulted due to partial resonance at triple frequency between line capacity and transformer reactance. The paper shows that, although not generally recognized, a triple component can exist in the line-to-line e.m.f. wave of a three-phase system. This is possible in a case where a two-to-three-phase transformation is used, and when the e.m.f. wave of the two-phase generator contains a triple harmonic. Vector diagrams and curves are given illustrating this possible effect.

IN CONSIDERING the relative advantages and disadvantages of Y and delta connections of transformer windings, it is necessary to pay some attention to the production of harmonic voltages and currents occuring in such windings due to hysteresis in the core. This has been treated by several since the present writer first drew attention to the effect,[1] but it may not be out of place in the present discussion to review briefly the conditions under which such harmonics become noticeable, and to point out a further possible case which, so far as the writer is aware, has escaped notice.

If we take the case of a transformer winding connected to an a-c. source of supply, we find that though the e.m.f. wave may be sine-shaped, the current wave necessary to produce the sine flux wave contains harmonics, notably a third and a fifth, which are produced by hysteresis and by the variation of permeability of the iron. These current harmonics may be regarded as in-

1. See the *Electrician* for 10th November 1905 and 5th January 1906.



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duced in the circuit by harmonic flux variations arising in the core. In such a case, however, the current harmonics produced "wipe out" almost completely the flux harmonic, because the resistance of the circuit is usually low. Hence the value of flux harmonic actually existing is only that sufficient to induce a voltage in the coil equal to $i \times r$, where $i$ is the harmonic current, and $r$ the resistance of the winding. By increasing the resistance, however, the flux and voltage harmonics become very noticeable, and a distorted wave form appears across the coil terminals. (Incidentally, this has an important bearing upon the use of series resistance for varying the voltage of an insulation—testing transformer, which sometimes results in the production of a high peak voltage. One remedy is to shunt a resistance across the transformer terminals, which allows of the use of a lower series resistance and therefore, reduced distortion). Without increasing the resistance, however, there is another way by which the current harmonic may be suppressed, viz., by the use of a star-connection of circuits, using the term "star" in its general senses implying $n$ circuits for an $n$-phase system. A little consideration shows that the $n$th harmonic of e.m.f. induced by the iron is directed in each circuit simultaneously towards or away from the neutral point, and that therefore no current of this frequency can flow. Hence, with a three-phase Y connection, the triple component of the magnetizing current is eliminated, and the full triple frequency flux variation occurs, producing a distorted wave form of high peak value, across each winding. With a Y-Y connection of transformers, particularly with single-phase transformers or shell type three-phase transformers, the full flux variation occurs. In the case of one set of windings, either primary or secondary, being delta connected, the flux variation is almost wholly suppressed by the circulation of the triple-frequency current in the closed triangle. From this point of view, therefore, a delta connection on either primary or secondary is desirable, as (1) It avoids the extra insulation stress due to the higher peak voltage, and (2) In the case of a transmission line with grounded neutral, it prevents triple-frequency capacity current in the ground wire, which, in the case of long transmission and high voltage, may reach a high value. In core-type three-phase transformers, the triple-frequency voltage is not marked, as the magnetic circuit of the flux harmonic is a partly open one, the path being up the three limbs in parallel and back through the air or tank. Oscillograms showing the

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conditions obtained in various cases were presented in an interesting paper by Mr. J. J. Frank, before the A. I. E. E. in May 1910. A case where trouble occurred which could only be ascribed to the above effects was brought to the writer's notice some time ago. The conditions were as follows:

From the power house, a five-mile 6600-volt line ran to a substation, where the voltage was raised to 12,000 by two Y-connected auto-transformers of 600 kv-a. capacity, with insulated neutrals. The 12,000-volt line supplied a substation five miles away, where step-down transformers were installed. Trouble was experienced due to the gap arresters on the 12,000-volt line continually sparking to ground. Also two breakdowns on terminal leads occurred, and there were other general indications of high voltage to ground, although the line to line voltage was correct. Voltage readings between the three lines and the auto-transformer neutral, on the 12,000-volt side, showed that with normal phase voltage on the transformer and the 12,000-volt line disconnected, the pressure between each 12,000 volt terminal and neutral was 17 per cent greater than the phase voltage $\div \sqrt{3}$. Then the 12,000-volt line was switched on, the voltage to earth rose further to 33 per cent above the normal value. Grounding the neutral of the auto-transformers cured the trouble, and reduced the voltage between the 12,000-volt lines and the ground to normal. It should be noted that the neutral of the generators was grounded through a low resistance at the power house. A ready explanation of these effects is afforded when the triple-voltage harmonics induced in the transformers are taken into account. With 12,000-volt lines disconnected, there is a 17 per cent increase of voltage to ground due to triple harmonic. This is aggravated, however, when the 12,000-volt line is connected, due to partial resonance, the capacity being in series with the high reactance of the auto-transformer winding. In this case the circuit is completed through the grounded generator neutral and the 6600-volt line. The effect of grounding is to connect the neutrals of generator and auto-transformer, and allow the triple component of current to be supplied, thus eliminating the voltage harmonic.

It has sometimes been stated[2] that no triple harmonic can exist in the e.m.f. between the lines of a three-phase system. It appears to the writer, however, that, though not often met with

2. See Steinmetz, Paper before N. E. L. A., June 1907., also Rhodes TRANS. A.I.E.E., 1910.

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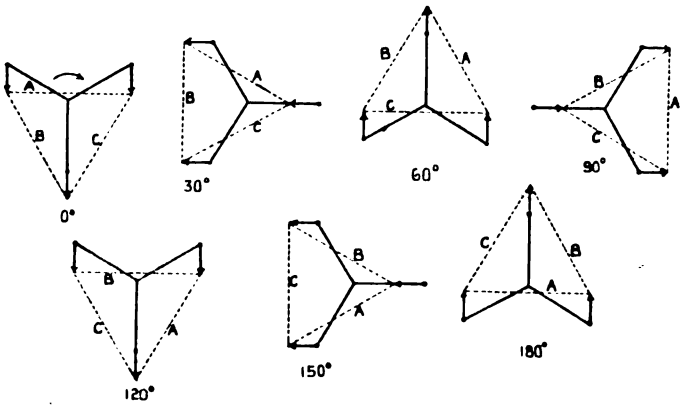
in practise, such an effect is quite possible. Consider the case of a two-phase generator supplying a three-phase line through Scott-connected transformers, and suppose that the generator




FIGS. 1-7—DIAGRAMS SHOWING TRIPLE HARMONIC IN THREE-PHASE SYSTEM AS PRODUCED BY THREE-PHASE GENERATOR OR BY Y-CONNECTED TRANSFORMERS—DOTTED TRIANGLE SHOWS LINE-TO-LINE E. M. FS.

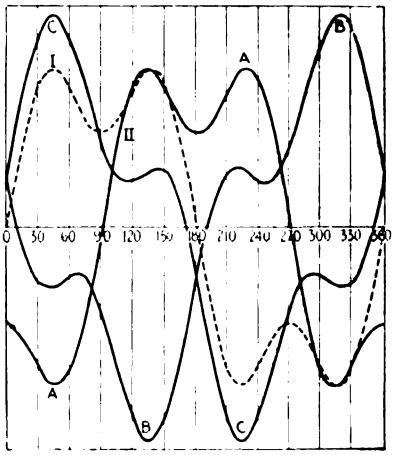



FIG. 8—WAVE SHAPES OF E. M. FS. BETWEEN LINES OF THREE-PHASE SYSTEM, SHOWING TRIPLE HARMONIC TRANSFORMED FROM TWO-PHASE SYSTEM.

Curves I and II two-phase e.m.fs. Curves A, B and C three-phase e.m.fs. See Figs. 9-15 for vector diagram.

e.m.f. waves contain triple harmonics. As the main waves differ by 90 deg. in phase, the harmonics in the two phases will differ 3 × 90 deg. or 270 deg. in phase, *i.e.*, they will be in quadrature. Hence we have a two-phase supply at triple frequency

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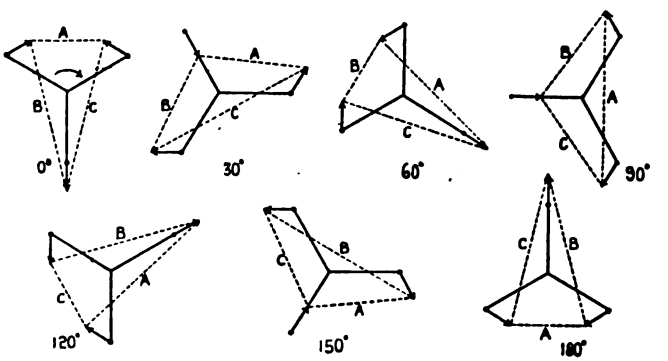
impressed upon the primary, and this is transformed to a three-phase e.m.f. at triple frequency which appears between the lines as a superposed harmonic on the fundamental three-phase e.m.f. It is a curious fact that this effect cannot be obtained by direct three-phase generation, but, apparently, only by transformation from a two-phase supply. The accompanying diagrams will make clear the difference between the two cases, viz., (1) Triple harmonic due to three-phase generator, or Y connection of transformers. Harmonic appears only between line and neutral, and not between lines. Figs. 1 to 7 show the vectors at progressively varying phases, during one-third of a cycle.

(2) Triple harmonic impressed on system by two- to three-phase transformation. Harmonic appears both between lines,




FIGS. 9–15—VECTOR DIAGRAMS SHOWING TRIPLE HARMONIC TRANSFORMED INTO THREE-PHASE SYSTEM FROM TWO-PHASE SYSTEM. (SEE FIG. 8 FOR WAVE SHAPES.)

and between each line and neutral. Fig. 8 shows the three-phase waves produced between lines, assuming particular values for the amplitude and phase of the triple harmonic in the two-phase e.m.f. Curves I and II are the assumed two-phase waves, having exaggerated harmonics. *A*, *B*, and *C* are the resulting three-phase line voltages. Note that these waves are dissimilar.

Figs. 9 to 15 give the vector diagrams corresponding to Fig. 8. The dotted line *A*, representing one of the three-phase line voltages, also represents by its projections on vertical and horizontal the two-phase voltages I and II respectively.

The writer is not aware of any previous reference to this possible effect, and it would be interesting to hear if such has been observed on any line employing two- to three-phase transformation.

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# RELATIVE MERITS OF Y AND DELTA CONNECTION FOR ALTERNATORS

BY T. S. EDEN.

ABSTRACT OF PAPER

The main advantages obtained with the Y connection are as follows:

(1) It is possible to bring out a lead from the neutral point of the winding, which is useful for various purposes.

(2) The cost is less than with the delta connection, requiring approximately 58 per cent of the turns.

(3) It is not possible for circulating currents of triple frequency to flow in the windings.

The delta connection does not appear to have any advantages except as a convenience in design for certain voltages. When used, proper precautions must be exercised in the design to eliminate excessive circulating currents.

THE FLEXIBILITY in design of three-phase machines, as compared with two-phase, lies in the possibility of using either the Y or delta connection.

It might be expected that either connection would be used indiscriminately, depending on which worked out best for the case in hand.

However, it is probably safe to say that over ninety per cent of the three-phase generators built are Y-connected.

The other cases are those in which, due to limitations in design as regards specified output, voltage etc., the delta connection permits the use of standard frames and tools, thus avoiding development. A few cases will also arise where customer's specifications call for the delta connection.

Some of the advantages of the Y connection are as follows:

(1) The possibility of bringing out a lead for various uses from the neutral of the winding.

This lead may be grounded. It may be used as the return in a four-wire system, giving with a 240-volt generator, the voltage between the neutral and the end of each phase for incandescent lighting; similarly, on a 4000-volt generator, giving 2300 volts for use with standard transformers for three-phase four-wire



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systems of distribution. In this latter case the neutral is generally grounded. This system is used in many large cities.

(2) The Y connection gives the required voltage with 58 per cent of the turns required by the delta connection. This is a large factor in cost, especially in machines of high voltage and large numbers of turns per coil, where the expense of internal insulation increases rapidly.

(3) In a Y-connected machine, with ungrounded neutral, it is impossible for currents of triple frequency or multiples of triple frequency to flow, since the third harmonics, existing in the two legs of the Y winding which are in series between a pair of terminals, are opposed to each other and of equal value, thus neutralizing one another.

In a delta-connected machine, the triple harmonics are in phase with each other, and will send triple frequency currents through the three phases in series of the closed delta. These currents are internal in the windings, the e.m.f. which causes them to flow being short-circuited in the closed delta, not appearing in the e.m.f. measured between terminals.

These circulating currents may be of great magnitude, entailing large $I^2R$ losses in the windings and corresponding loss of efficiency.

(4) In general, for the average alternator, the e.m.f. wave of the Y-connected winding is nearer a true sine than that of the delta-connected generator.

(5) The use of the grounded neutral reduces the potential strain on the insulation of the windings, permitting reduced thickness of insulation.

The above indicate the merits of the Y connection.

On the other hand the delta connection does not appear to have any advantages. When used, care must be exercised in design, paying attention to the percentage of pole-face width to pole pitch, shape of pole face, saturation of the magnetic circuit, etc.

Fig. 1 gives the wave shape of the e.m.f. on closed delta of a 900-kv-a., 25-cycle, 400-volt unit, in which it was found that the circulating current at excitation for no-load full voltage was 83 per cent of full load current.

At 75, 87.5, 100 and 112.5 per cent of full voltage no-load, the circulating current was found to be 59, 69, 83 and 107 per cent, respectively, of full load current.

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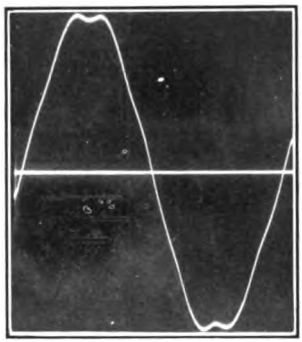

[EDEN]

FIG. 1—POTENTIAL WAVE OF 900-KV-A. 25-CYCLE, 400-VOLT GENERATOR, CLOSED " DELTA ".

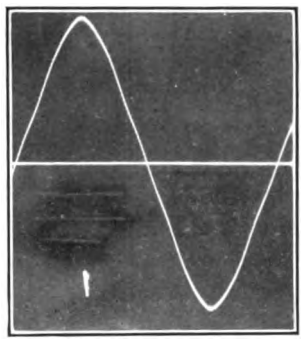

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FIG. 2—POTENTIAL WAVE OF 900-KV-A., 25-CYCLE, 400-VOLT GENERATOR, OPEN " DELTA ".

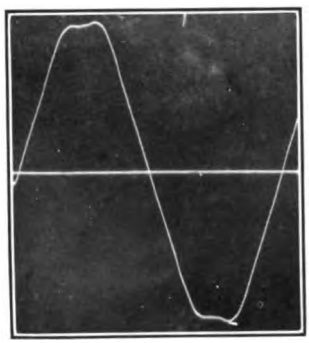

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FIG. 3—POTENTIAL WAVE OF 7.5-KV-A., 60-CYCLE, 110-VOLT GENERATOR CLOSED " DELTA ".

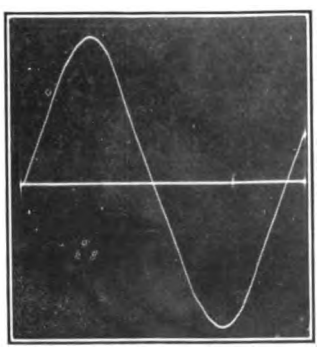

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FIG. 4—POTENTIAL WAVE OF 7.5-KV-A., 60-CYCLE, 110-VOLT GENERATOR, OPEN " DELTA ".

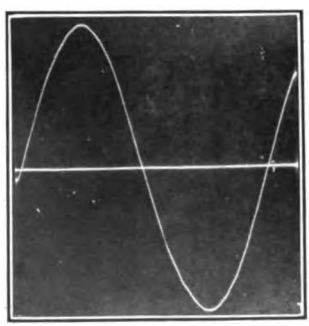

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FIG. 5—POTENTIAL WAVE OF 7.5-KV-A., 60-CYCLE, 110-VOLT GENERATOR, ACROSS TERMINALS CONNECTED Y.

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The analysis of this wave shape shows the equation of the curve to be

$$\begin{aligned} E = &+ 99.9 \sin(\alpha - 0.01 \text{ deg.}) \\ &+ 1.0 \sin(5\alpha + 36 \text{ deg.}) \\ &- 1.8 \sin(5\alpha + 4 \text{ deg.}) \\ &+ 2.9 \sin(7\alpha - 16 \text{ deg.}) \\ &+ 0.2 \sin(9\alpha + 59 \text{ deg.}) \\ &- 1.1 \sin(11\alpha + 72 \text{ deg.}) \\ &- 0.3 \sin(13\alpha - 45 \text{ deg.}) \end{aligned}$$

Similarly, Fig. 2 shows the wave shape of e.m.f. taken across one leg of the delta, one corner of the delta being open.

The analysis of this curve gives the equation

$$\begin{aligned} E = &\ 99.9 \sin(\alpha - 0.1 \text{ deg.}) \\ &- 5.9 \sin(3\alpha - 9 \text{ deg.}) \\ &+ 0.3 \sin(5\alpha + 28 \text{ deg.}) \\ &- 0.1 \sin(7\alpha - 86 \text{ deg.}) \\ &+ 1.1 \sin(9\alpha + 8 \text{ deg.}) \\ &+ 0.1 \sin(11\alpha + \text{ deg.}) \\ &+ 0 \sin(13\alpha + 0 \text{ deg.}) \end{aligned}$$

In the former the percentage of third harmonic is small as compared with the latter, the e.m.f. being used up in overcoming the internal impedance of the machine. However the fifth and seventh are strong, being produced by the pulsations of the field set up by the circulating current in the delta. The latter shows a third harmonic approximately 6 per cent of the fundamental, the others being practically negligible.

The Y connection constructed by adding two waves like Fig. 2, displacing them 60 deg., gives practically a sine curve. The use of a Y connection in this instance would have effected a saving of over 1 per cent in efficiency at full load.

Similarly, curves in Figs. 3, 4 and 5 show e.m.f. waves of closed delta, open delta and Y connection on a 7.5-kw. alternator in which the circulating current was a large percentage of full load current.

A further example of the effect of saturation on circulating current is seen in the following table, made up from tests of a 3000-kv-a., 6600-volt, 112 rev. per min., 60-cycle generator, connected delta for testing purposes.

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| Per Cent Full Volts Per Phase | Circulating Current in Per Cent of Full Load Current |
|---|---|
| 57 | 6 |
| 77 | 7.7 |
| 87 | 8 |
| 94 | 7.7 |
| 107 | 3 |
| 115 | 0 |

By using a $66\frac{2}{3}$ per cent pitch winding, with the delta connection, the third and multiples of the third harmonic are eliminated. (See TRANS. A. I. E. E., Vol. 28 (1909) page 1064.)

Thus in a 2500-kv-a., 2300-volt, 133-rev. per min., 60-cycle generator delta-connected, using $66\frac{2}{3}$ per cent pitch, an ammeter

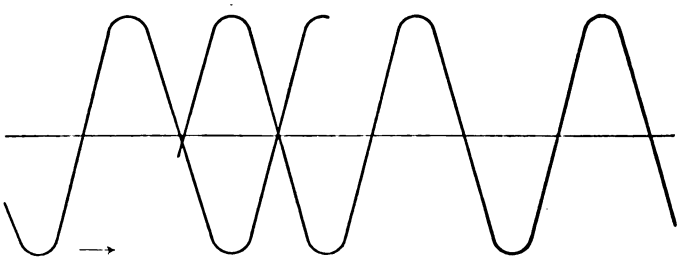

FIG. 6—POTENTIAL WAVE OF 2500-KV-A., 60-CYCLE, 2300-VOLT GENERATOR, OPEN DELTA.

in the corner of the delta gave no reading. The wave shape taken across one leg of the winding, with the delta open, is shown in Fig. 6.

It would therefore seem that from the standpoint of the designer, the Y connection is the safest to use and that great care must be exercised in using the delta connection.

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*Presented at the 2nd Midwinter Convention of the American Institute of Electrical Engineers, New York, N. Y., February 27, 1914, under the auspices of the Electric Power Committee.*

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# THE PRESENT STATUS OF ALUMINUM-CELL LIGHTNING ARRESTERS

BY E. E. F CREIGHTON

ABSTRACT OF PAPER

This paper gives a brief survey of the conditions of operation of aluminum-cell arresters, without any description of the forms of the arresters. References are made to recent investigations of lightning phenomena and their possible effects on the design of protective apparatus used at present. The d-c. aluminum arrester is most economical and represents the highest possible grade of protection. In connection with the a-c. aluminum arrester the following points are discussed: dielectric spark lag, dissolution of film, charging resistance, oscillations, damping, degrees of surges due to natural operations and accidents, and insulations which withstand these surges. Charging resistance on aluminum arresters is chosen to make surges harmless, and the charging resistance gives great immunity from damage to the arrester itself by any accidental and temporary local condition in the arrester. In conclusion, the aluminum-cell arrester may justly be regarded as a standardized electrical device founded on solid fundamental principles.

ALTHOUGH the aluminum-cell lightning arrester is now many years old in practise, there is available in the TRANSACTIONS of the Institute very little definite scientific information on this subject. It has seemed preferable to produce certain results rather than describe beforehand how such results were to be obtained. The practise of the aluminum arrester has now settled down to definite sets of conditions, and it is the object of this paper to consider standard conditions and open up the subject to discussion. Aluminum lightning arresters will be treated in general on points that may seem debatable. No detailed description of apparatus will be given herein.

The question is often asked—Will certain types of arresters be superseded? In very few cases has it been possible to give a definite answer to such a question, owing to incomplete knowledge of cloud lightning phenomena. It has been possible to say that if future investigations of cloud lightning prove that every lightning stroke is of high frequency and steep wave front, certain changes would come about under these conditions; it



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would be possible to prophesy, with considerable confidence, that many types of lightning arresters now in use would disappear. The natural growth of protection would be along the line of various types of high-frequency absorbers.

If, on the other hand, it should be shown that lightning is always of low frequency, and gives the surge a sloping wave front, then again, it would be fairly safe to prophesy the contrary—that very few of the lightning arresters now in use would disappear, and that probably no other devices would take their place.

Recent investigations of lightning phenomena have confirmed our views that cloud lightning has wave fronts of various degrees of steepness, and without question some of the lightning strokes are not high-frequency effects but are of the nature of simple impulses. The writer's recent experiences along this line have been gained by indirect methods. Lightning arresters have been put out which were sensitive to very high frequencies, and at high frequencies had very good protective qualities; but at very low frequencies their spark potentials were greater than at high frequency. Other arresters equally sensitive to both high and low frequencies have been installed in the same locality. This experience has indicated that many of the strokes are of low frequency. The most valuable and practical investigation of lightning arresters that has yet been made on a large scale has been carried on by Mr. D. W. Roper, and no doubt these results, which are incomplete at the present time, will be made available at some later date. More direct measurements of lightning taken with an oscillograph have been made by Mr. L. A. De Blois. These, I believe, are the most valuable direct tests that have been made in many years. I am personally indebted to both Mr. Roper and Mr. De Blois for information on their researches, and I understand that their valuable work will be presented to the Institute at some future meeting.*

In the development of the present standard arresters our knowledge of lightning gave us no alternative but to assume that lightning had all the characteristic qualities of the various surges that could be produced in the laboratory. For example, we have assumed:

That the frequency might be from zero to 5,000,000 cycles per second.

*See paper by L. A. DeBlois, *Some Investigations on Lightning Protection for Buildings*, PROCEEDINGS A.I.E.E., April, 1914, page 563. (Presented at Washington, D.C., April 24, 1914.)

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That the wave front might be either vertical or angular.

That the quantity of electricity was both large and small.

We have known from our earliest investigations that several strokes came in succession. It was also necessary to take into account the effects of the energy from the generator which followed the lightning discharges. In this way we have endeavored to be prepared to meet any new information that might come concerning lightning strokes. Naturally, all these different factors could not be given equal weight in the design, and therefore, as more definite information regarding the nature of lightning is obtained, the designs will be strengthened in the features that these investigations may show are weak. It is a matter of increasing the ultimate efficiency by a small percentage.

The direct-current aluminum arrester is practically ideal from the standpoint of protection. It has no series gap and therefrom it gains two valuable characteristics: the first of these is the elimination of any dielectric spark lag; and the second is the absorption of high frequencies which have a less potential than the circuit potential. Commenting on these two conditions, the dielectric spark lag, although it is ever so small, is still appreciable as compared with the time of movement of a surge along overhead lines. A surge will travel a mile (1.6093 km.) in about five millionths of a second. If the surge is a mile long, and the dielectric spark lag is five millionths of a second, such a surge will have passed along the line without starting a spark across the gap. The only means of discharging such a surge would be by introducing a choke coil in its path and thus delaying its movement sufficiently to allow the spark gap to become ionized. Since the spark gap of the a-c. aluminum arrester has a setting which may be only 25 per cent above the line potential, high-frequency surges can be deflected into the arresters if the potential either of the surge or the superposed value on the 60-cycle potential reaches the spark value. If the generated potential happens to be zero at the instant, it is evident that the surge itself must have a value 25 per cent above normal in order to cause the arrester gap to spark. The d-c. aluminum arrester, by its direct connection, is able to pick up surges of all frequencies and all potentials immediately on their arrival at the terminals of the arrester.

The practical demonstration of the protection afforded by these d-c. aluminum arresters confirms the theoretical work and experimental tests made on the cells. The discharge rate at

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double potential is more than a million times as great as the leakage current at normal potential.

From a practical standpoint, the cost of such arresters must be considered. While the cost and upkeep of the d-c. aluminum arrester is greater than for the older types using gaps and series resistances, still the aluminum arrester is the more economical one to use. The higher protection given by the cells would justify some increase in expense on account of the better service that can be maintained. But, as a matter of fact, the actual expenditure for the protection as a whole becomes less, due to the fact that good protection on the cars makes a less demand for the use of arresters along the trolley line. The saving in the cost of line arresters will more than compensate for the extra cost and upkeep of the aluminum arrester. Moreover, even with the very best types of gap arresters on trolley cars and trolley lines it is impossible in lightning-infested districts to maintain the car service. The percentage of protection from the gap type of arresters is not high enough even when the best arrangement of wiring and choke coils is used in conjunction with the arresters.

There is one further function of the d-c. aluminum arrester that has considerable value, and that is the absorption of electromagnetic surges coming from the interruption of accidental short circuits on the trolley line. Such high potential across loaded motors has a tendency to cause flashing around the commutators. If the flashing around the commutator is caused by the excess potential, then the d-c. aluminum arrester will relieve the trouble.

Answering, then, the frequently asked question—Will the d-c. aluminum arrester be superseded?—the answer is, in principle, no. Improvement in details may be made, and there may be discovered some new and better substance than the aluminum film, but none is yet known. Any degree of protection that is desired at its terminals can be obtained by the use of this arrester. An improvement in the length of life of the arrester is desirable, but this will not be superseding it. The discovery of some new substance that will give the same electric valve effect at a definite voltage only slightly above the operating voltage would be no particular improvement, unless perhaps it might be something that would not deteriorate when left disconnected from the circuit.

Turning next to the a-c. aluminum arrester, it was found impracticable to maintain simplicity and long life in the arrester

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and at the same time keep the arrester directly connected to the circuits. For this reason the horn gap was introduced in series with the aluminum cells. Since the hydroxide films on the aluminum plates gradually dissolve in the electrolyte it becomes necessary to introduce a method of charging the cells. The simplest method was first tried: it consisted of bringing the horns near each other and reducing the gap to a very small value. Many trial installations were made under these conditions and no bad effects were obtained. When the number of arresters in use ran up into the thousands, then an occasional trouble resulted from the rush of current into the aluminum cells.

The aluminum cells are condensers and as such will take initially a considerable rush of current. Furthermore, the dissolution of the aluminum films required a considerable quantity of electricity from the line to reform them. Where the films had been subjected to unusual dissolutions either by standing in hot electrolyte, resulting from atmospheric temperature or long periods of discharging, or from neglect to charge, the current rush into the aluminum cells became a serious menace, mostly to the arrester itself. Since there is no external indication of a bad condition of the aluminum cells, even an expert would be unable to know if it were permissible to close the charging gap of the arresters. This led naturally to the use of charging resistances in series during the ten seconds a day needed to charge the arrester. The charging resistance is an added expense and an added complication. But the added complication is relatively small, and the all-around increase in the safety of the arrester is great enough to justify both the cost and complication, from the user's standpoint.

The subject of possible surges accompanying the charging of aluminum arresters is one far more pertinent in an article written for foreign readers than in one for American engineers. The foreign operators seem to have had misfortunes with their arresters that have not been duplicated in America. The reason for this might be attributed to a number of different causes, depending upon the country and the localities. These reasons might be enumerated as methods and care in manufacture, the lack of definite and emphatic instructions to operators, poor distribution of insulation in transformer coils, and difficult situations caused by any one of several factors, such as, for example,—high temperature, bad regulation of the line, and insufficient care after an arrester had been called on to discharge continuously during an accidental ground.

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The general results from any one or more of the foregoing enumerated factors may be classified under two heads: first, a short circuit in the arrester and consequent interruption on the line; and second, surges set up on the line without any damage to the arrester. Nearly all these conditions can be rendered harmless by the use of charging resistances. The one important exception is the matter of bad regulation of a line in which the power voltage is allowed to rise to values above the spark potential of the arrester. Under these conditions of discharge the arrester is no longer being used as such, but rather as a rheostat to absorb the generated power. The arresters cannot, at any reasonable expense, be designed to act as rheostats. While it might, in special cases, be possible to develop arresters which would withstand these conditions, the better solution of the problem is to improve the regulation. If care in manufacturing the aluminum plates and the electrolyte is not taken, and the installation made free of dirt and impurities in the electrolyte, more or less deteriorated conditions will exist throughout the life of the arrester. Certain kinds of impurities have a strong destructive effect on the films. A condition of unusually high operating temperature may call for an electrolyte especially adapted to high temperatures, or it may simply be taken care of by charging two or more times a day. Dissolution of the film from standing in hot electrolyte after the arrester has discharged continuously for a number of minutes can cause no trouble if a reasonable charging resistance is used, as the series resistance limits the current to a value which will not damage the arrester. With the exception, then, of high generator potentials from bad regulation of voltage, there is no difficult problem connected with the use of aluminum arresters.

A discussion of the aluminum arresters would not be complete without some reference to the possible surges that may be set up by the charging of the arrester. Surges on an electrical system may be considered in a list of ascending degrees of severity. Turning on an incandescent lamp sets up an electric wave on the system by calling on the generator for more power. A surge of this kind is of the third order of importance, and therefore, entirely negligible. It is well known that any spark or arc in the circuit containing inductance and capacity tends to set up oscillations, but if the resistance in series is equal to, or greater than, the critical resistance, oscillations will be prevented.

It is common practise to-day to open and close circuits which

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contain inductance and capacity without introducing in series a resistance to absorb the transient surges that are thereby set up. It is also common practise to-day to use circuit breakers to open accidental short circuits in which there is a high value of surge energy, and sometimes high voltages.

Going still a step further, every circuit is subject to accidental arcing grounds, which produce continually on the circuit dangerous surges which are often but slightly damped. It is difficult to protect apparatus from these most severe conditions of surges. In general, however, apparatus is built to withstand severe treatment, and there is but a small percentage of loss. Therefore, when we come to consider surges on the system we should take into account the conditions of insulation in relation to the severity of the surge.

In all these graded degrees of severity of surges, where should the aluminum arrester be placed? If there were a demand for it, the arrester could be placed in the list next to the negligible surge of connecting an incandescent lamp to the circuit, and this could be accomplished by using graded resistance in charging. In view of the insulation of the apparatus that is needed for the usual condition of operation and to withstand the inevitable accidents which cause severe surges from time to time, the use of graded charging resistance would be a needless and inconsistent precaution. It is sufficient to say that it could be done if it were desired.

What is actually done is more reasonable. A relatively large value of resistance is used in the charging circuit, limiting the current to a range of 5 to 15 amperes. Charging resistances are an intrinsic part of aluminum arresters as now manufactured. Strong recommendations have been made to operators to add them to their older arresters. A characteristic answer is to the effect that " our arresters have been charged through a gap for six years without trouble, and we are satisfied." The change is brought about not by reason of surges, unless they cause telephone interference, but rather on the ground that the arrester is made more immune from damage to itself.

In foreign countries, with their water jets and resistance types of arresters, the controversy over arresters still waxes as warm as it did here in the formative period some eight or ten years ago. The following argument is advanced against the aluminum arresters: admitting that the charging resistance does away with the surges, what about the heavy strokes which cannot pass

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through the charging resistance and therefore jump the main gap directly into the cells to ground? To anyone familiar with the practise here up to 1913 an answer is unnecessary. If this discharge path were a menace, devices could be used to mitigate it. The nature of the menace can be understood by a review of the past practise. There are several thousand aluminum arresters in use that have been charged through a gap without series resistance. Good practise now condemns the method, but there it is. Ten seconds' charge a day produces over a thousand makes and breaks. There would therefore be more than a million total made per day and more than a billion in a few years. Judging by the rare cases of trouble in this vast number it cannot be much of a risk to allow a few discharges per year to pass directly to ground through the aluminum cells, especially in face of the fact that such a surge is so dangerously large that it cannot be relieved through the resistance, and therefore the surge itself is an undoubted menace to the insulation as it runs wild over the electrical system at 186,000 miles per second.

The status of the aluminum arrester, therefore, is that of a device founded on the solid principle of a safety valve. It has definite limits of maximum current discharge rate and of energy absorption, beyond which damage to the arrester will result. In this respect it is no different from other standard apparatus. Years of experience have demonstrated that these limits are far above the usual demands of practise, but naturally it is not impossible to pass them. The flexibility to meet special conditions is great. Film area, internal resistance, relative gap settings, external resistance—all are readily adjustable to the demands which may possibly come as our knowledge of lightning and other surge phenomena is increased.

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# ELECTRIC POWER

BY DAVID B. RUSHMORE AND ERIC A. LOF

ABSTRACT OF PAPER

The authors briefly trace the evolution of electric power up to the present time, and note various fields of application of electric power which have become specialized branches of electrical engineering.

The tendency of public utilities towards consolidation, and the advantages to be derived thereby, are discussed, also the interconnection of hydroelectric plants, and the grouping of systems under a holding company. The growth of the electric power industry is illustrated by reference to the recent U. S. census report.

The present practise tends to the use of very large generating units, and transmission lines are being constantly increased in length and operated at higher voltages. Applications of electric power to various industries are briefly referred to and their advantages in various fields are specified.

THE present situation of electric power is best seen in perspective; it is one amongst many forces which have played a part in the development of our civilization. Looking for an instant back to the dawn of history, which began with articulate speech, we discern a number of factors which played an important part in the development of the human race. After communication through speech was developed, the use of fire, the invention of the bow and arrow, the development of pottery and the domestication of animals, together with the development of irrigation and the use of bricks and stones for buildings, led up to the important change brought about by the smelting of iron. Since that time the invention of writing, of gunpowder, the mariners' compass, of paper and the printing press, of spinning and weaving, and, finally, of the steam engine, have brought civilization to the middle of the last century.

With the development of the steam engine came the introduction of an entirely new factor into civilization, that is, the manufacture of power, and the ability to utilize in forms applicable for substitution for the physical work of man the stored energy of our natural resources. The development of the industrial life is necessarily dependent upon the manufac-



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ture of power, and its beginning is a feature of the century which has just closed.

With the latter part of the nineteenth century there came about what may properly be termed the beginning of an age of electricity. Power manufactured from water-falls or from coal piles had decided limitations regarding its use, which was necessarily confined to the immediate vicinity of the place where it was produced. Energy in the form of coal is, of course transportable, so that the industrial centers were not necessarily limited to the vicinity of coal mines, but the methods of transmission of power being almost entirely by means of shafting, belts, ropes, chains, gears, etc., the distance over which power could be efficiently transmitted was small.

The age of electricity which has brought with it the possibility of transmitting electrical energy over great distances has allowed the development of remote and inaccessible water powers, the energy of which has been utilized in the most favored locations. It has also allowed the power generated from steam engines to be concentrated in large power houses, and to be transmitted over distances approaching those in use with water powers. The effect of this development has been wonderful, and at the same time not easily discernible.

Electricity plays an important part in our present civilization along four principal lines—communication, transportation, illumination, and industrial power in its broadest sense. At first, the use of power made a slow progress, but its present rate of increase is very large. The original man used his own muscles and later co-operated with a number of others where his single effort was unavailing. Through slavery he brought to his own use the power of a number of men, and later domesticated animals.

Water powers were the first real development outside of animal life, and there are still many industrial centers grouped around these early installations, such as is evidenced by many of the old New England manufacturing centers.

Suddenly at the end of this long period has come the development of the steam engine and its child, the steam turbine, with its applications to transportation on land and water, and for general industrial power purposes, followed by a variety of developments of gas, gasoline and oil engines.

Energy available for the use of man comes to us either from the sun or from the rotation of the earth. For practical con-

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sideration the second can be neglected, and the energy of the water powers, of the coal, gas and oil deposits furnish our source. Through such prime movers as water wheels and various forms of engines and turbines this energy becomes available in mechanical form, but is in many cases not well suited for general application.

Electricity is not in itself a source of energy. It is obtained either directly or indirectly, by transformation from energy in either a chemical or mechanical form, and in all practical cases is again transformed before being utilized. Electricity therefore plays the function of being the most convenient form in which, for many purposes, energy can be transmitted and distributed.

For all power purposes electrical energy is converted into mechanical energy by means of an electric motor driving a machine. In its application to the transportation of people and commodities we employ it to a growing extent on our main railroads, on our interurban and city railway systems, on automobiles of either the storage battery or trackless trolley type, and on elevators. For manufacturing purposes electricity is converted into chemical energy in various electrochemical processes, into heat for its use in electric furnaces, cooking and heating apparatus of various kinds, and, as before mentioned, into mechanical energy by electric motors driving a wide variety of industrial machinery.

A subdivision of the various fields of activity in connection with electrical work is possible along a number of different lines. The specialization of the use of electricity has proceeded to such a point that a certain desirability of grouping is apparent, and that adopted by the International Electrical Congress is a very suitable one. This is as follows:

1. *Generation, Transmission and Distribution.* Central station and substation design, control and operation. Long distance transmission of electric power.

2. *Apparatus Design.* Generators, motors and transformers. The rating of machinery.

3. *Electric Traction and Transportation.* City, surface and rapid-transit railways; interurban and trunk lines; electric vehicles, ship propulsion, mining railways, elevators and hoists.

4. *Electric Power for Industrial and Domestic Use* Factories, Mills, refrigeration, heating devices, etc.

5. *Lighting and Illumination.* Arc and incandescent lighting; the science and art of illumination.

6. *Protective Devices: Transients.* Switches, circuit breakers; condensers; electrostatics; disruptive phenomena; high-frequency phenomena.

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7. *Electrochemistry and Electrometallurgy.* Electrolytic and metallurgical apparatus and processes.

8. *Telegraphy and Telephony.* (a) All communication of intelligence by the use of wires. (b) Electromagnetic waves and radio-telegraphy and -telephony.

9. *Electrical Instruments and Electrical Measurements.* Switchboard, portable, standard and absolute instruments.

Testing and standardization methods; absolute measurements.

10. *Central Station Economics.* Load factors, power factors, measurement of maximum demand and all problems affecting the economy of central stations; also rates, their regulation and legislation.

11. *Electrophysics.* Radioactivity; Rōntgen rays; gas and vapor conduction; electron theory; constitution of matter, etc.

12. *Miscellaneous.* Such as history and literature of electrical engineering; symbols and nomenclature; engineering education and ethics.

The field of electrical activity having become so great that it is impossible for any one individual to follow the different lines in all their details, it becomes desirable to so group the subjects as to bring together in one class those of interest to one group of individuals.

The problems of generation, transmission and distribution of power are so interwoven in their engineering aspects as to preclude of any natural separation of treatment, and therefore inevitably these three subdivisions fall together in one class and include the general subjects primarily associated with the activities of the public utility. The question of the utilization of power, especially in its details, is often something with which the public utility is not concerned and properly falls into a different grouping.

With the continued growth of the Institute and the necessity for a rearrangement in its organization of technical committees, it has been seen that the Electric Power Committee would best include such subjects as might properly fall under the heads of at least three sub-committees on the generation, transmission and distribution of power.

The generation of electrical energy naturally includes all of the questions involved in the conversion of potential into mechanical energy, and from mechanical into electrical, involving questions of power station and prime movers. The transmission of electrical energy would naturally include all of the electrical and mechanical features of transmission lines and such factors as may incidentally be involved, while the distribution of electrical energy may be said to bring it up to the point of application to the consumer.

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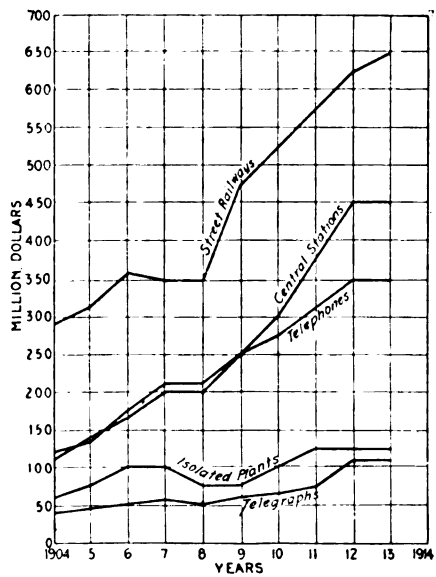
Public utilities are now undergoing very great changes. There is a strong tendency toward consolidation with a view of concentrating the power supply for all uses in a large territory from one system. So, for example, a supply company in a large city expands so as to embrace the whole district around it, and service given originally within a small area is unified over hundreds of square miles. In other cases the properties in a given territory are merged and brought under one management. This is strikingly illustrated by one large public service company in the Middle West where nearly one hundred com-




EARNINGS OF PUBLIC SERVICE COMPANIES

munities were originally supplied by about fifty separate generating stations. These have now mostly been shut down and four modern stations will ultimately furnish all the power needed for this service.

The interconnection of hydroelectric transmission systems is also a step in the right direction, as demonstrated in our Southern states where half a dozen large systems are tied together, furnishing power to each other on an "interchange" contract basis. The advantages of this are obvious. The peak loads of the different systems may not coincide, the minimum stream flows may occur at different times on the different

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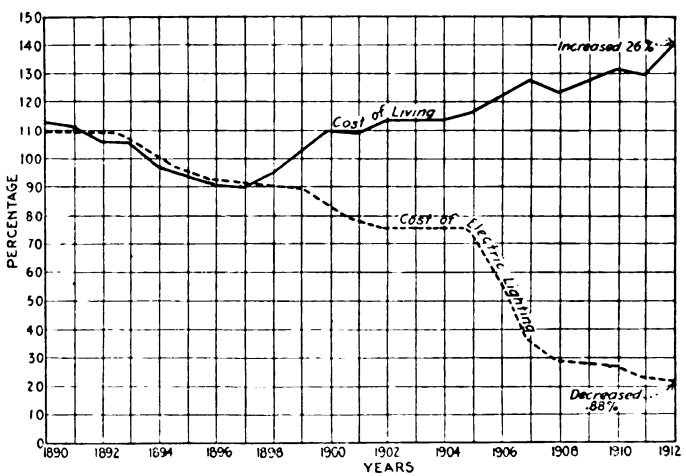
water-sheds, common steam reserve stations may be used, and in general the operation may be so improved that a most efficient and reliable service can be rendered to the customers of all the systems so tied together.

In some cases groups of established systems although located in vastly different localities may be brought together under one holding company, and to the creation of such companies may, in many instances, be attributed the high-class service and financial success of our small and medium size light and power systems. The economies due to a central management, the benefits of the best technical and expert advice applied even to the smallest central station, the cumulative effect of active




THE COST OF LIVING AND ELECTRIC LIGHT

up-to-date new business campaigns at every point, all have contributed to an improved and cheaper service to the consumer, and without the facilities of such a control they could exist only in the larger communities. Another very important advantage is the great problem of financing all these undertakings and providing funds for extensions to meet the ever growing demand of the public for electric service. It is, possible, in providing ready financial facilities for these purposes that the holding company performs its most important function.

In order to give the people the best service and the lowest rates all public utilities must of necessity be natural monopolies, and the public service regulation is a recognition by the state

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of the essentially monopolistic character of these enterprises. The favorable showing of virtual monopolies in reducing the cost of electric power is due mainly to a reduction in the capital expenses, lower operating costs and in no less degree to the reduced risk to the investor. By effective safeguards and a well-considered policy of public control the electric securities have become one of the most desirable investments, and there is every indication that efficient public service regulation will make possible even further reductions in the cost of electric power production of public service utilities.

The quantity and quality are the principal elements which determine the value of an electric power service, and while the quantity can readily be measured, there is no standard of quality. It is generally a very difficult matter to determine what under given conditions is good service, and whether the quality of the service that has been specified is actually rendered. An absolutely reliable service can of course be obtained, but at a very high cost which is justified in only very rare cases. In general, the more reliable the service is the more it must cost, due to the superior construction required and to the increased investment for emergency apparatus, etc. The question, therefore, always arises, what degree of reliabliity is justified under certain conditions and what is the real value of such service. It is evident that it varies very widely for different industries.

The load factor has a very important bearing on the cost of producing electric power, and great efforts are now being made everywhere to improve it. The yearly load factor for any class of service is determined largely by seasons, the habits of the people, and similar conditions which do not change very materially. Improvements in the load factor must therefore be obtained by the addition of industrial loads, and by combining different classes of service, the maximum demands of which occur at different times of the day or the year. Many central stations today sell far more energy for power than for light, and the Commonwealth Edison Company of Chicago is an admirable example of what can be accomplished. This company has a very large industrial power load and is today carrying a larger railway load than any other central station in the country, with the result that it is operating at the exceptionally high load factor of about 44 per cent. When the steam railroad terminals have been electrified, and if this load could be obtained, it is estimated that the load factor could be still further increased to about 50 per cent.

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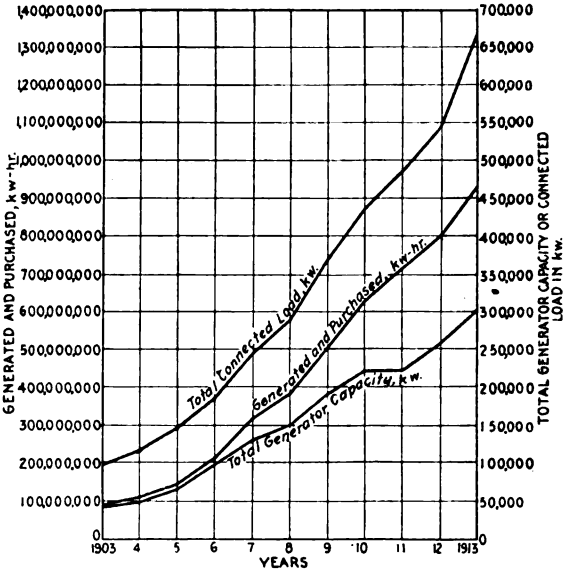
The tremendous up-swing of the electric power industry during the past decade is best realized by a reference to the recent census report for central electric light and power stations. In 1902 there were 3620 such stations with a total capacity of 1,212,235 kw. and an output of 2,507,051,115 kw-hr. In 1912 these values had increased to 5221 stations with a total capacity of 5,134,689 kw. and an output of 11,502,963,000 kw-hr.

For the generation of this power the steam turbine and the water wheel stand foremost and it is an astonishing rate at which the size as well as the efficiency of these generating units




THE GROWTH OF THE COMMONWEALTH EDISON COMPANY, CHICAGO

has increased of late. A 35,000-kw. steam turbine unit is now under construction and is the largest single unit turbine built up to the present, although there is every indication that the 50,000-kw. mark will be reached before very long. Hydro-electric turbine units are now also built for capacities up to 17,500 kw. and a large number of notable water power installations have been recently completed or are under construction. Among these may be mentioned the 300,000-h.p. development of the Mississippi River Power Company at Keokuk, Iowa; the Big Creek developments of the Pacific Light and Power Company, California, and many others.

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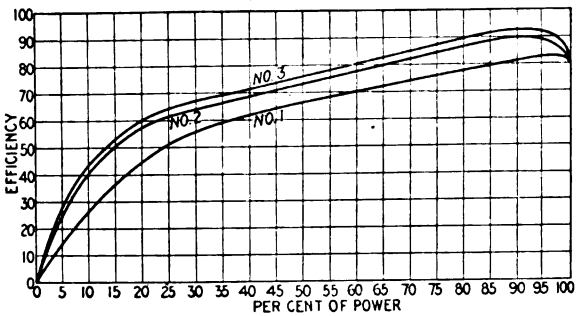
HORSE POWER OF PRIMARY POWER MACHINES.

| Kind of Power | Central Stations. | | | Manufacturing Industries. | | |
|---|---|---|---|---|---|---|
| | 1902 | 1907 | 1912 | 1899 | 1904 | 1909 |
| Total..... | 1,845,048 | 4,098,188 | 7,528,648 | 9,728,433 | 12,762,642 | 16,778,813 |
| Steam Engines and Turbines | 1,394,395 | 2,693,273 | 4,946,532 | 8,139,579 | 10,825,348 | 14,202,137 |
| Gas and Oil Engines..... | 12,181 | 55,828 | 111,035 | 134,742 | 289,423 | 754,083 |
| Water Wheels.. | 438,472 | 1,349,087 | 2,471,081 | 1,454,112 | 1,647,871 | 1,822,593 |

For the transmission and distribution of electric energy the voltages continue to increase, this in turn presenting new problems of design and construction. The important problem seems to be the fitting in of new developments embodying the




RECENT DEVELOPMENTS OF HYDRAULIC TURBINES

No. 1. Efficiency and power obtained from two-runner turbine in 1906.
No. 2. Efficiency and power from Holyoke test of modern high-speed runner.
No. 3. Efficiency and power possible from modern single-runner turbine, with runner as per curve No. 2 installed, same speed as No. 1.

best of present-day designs, with parts of an existing system. Here the increase in size of generators, transformers and of generating stations and interconnected substations with their distributing lines, makes the transmission of electric power as interesting as it is complex.

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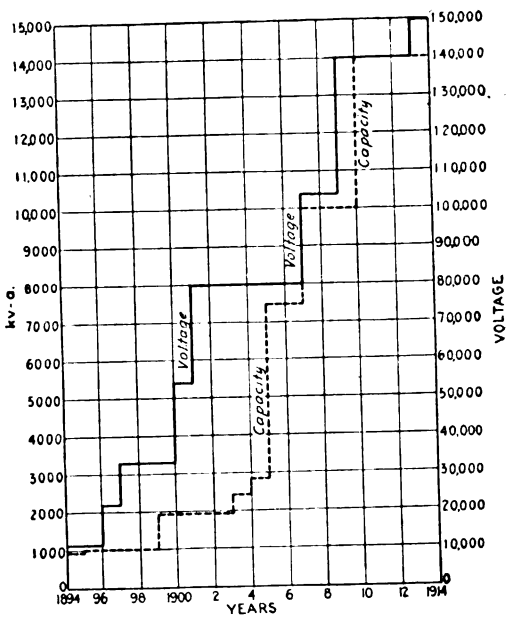
A large number of high-voltage transmission systems have thus been extended so that they are really high-voltage distributing systems, and the problem then presents itself as how to take off small amounts of power economically. The success attending the installation of large outdoor substations has therefore also created a demand for a simple form of substation structure and equipment to enable the taking off of small amounts of power from high-tension lines. Such equipments must necessarily be installed and maintained at a cost that is




TRANSFORMER DEVELOPMENT

in keeping with the revenue that can be expected from the load which is to be taken off.

Water power was used more extensively than steam in the manufacturing industry prior to 1870. Since that time, however, it has steadily declined, while the use of steam power increased, reaching a maximum of 78.2 per cent in 1900. There has since been a marked falling off in the percentage of directly applied steam power and this has been due to rapid introduction of electric power. The increased use of the electric motor for driving industrial machinery has been phenomenal and this

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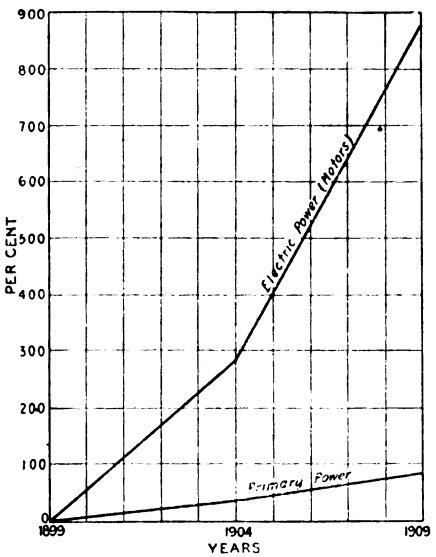
is best illustrated by a reference to the census report. For example, for the period of 1899-1909, while the primary power increased about 80 per cent, the application of electric motors for manufacturing industries alone increased close to 900 per cent. For street railways the change has been even more marked in that the steam and animal power has been almost entirely superseded by the electric motor drive. The tendencies illustrated by the above changes that have taken place in the method of utilizing electric power, apply in general to a large number of industries.

The advantages of using electric power for mining operations




COMPARATIVE GROWTH OF POWER USED IN MANUFACTURING

are now fully recognized and almost all new mines are being equipped for electric drive, and a very large number of old ones are changing over to this system. Not only does this reduce the cost of working, but it also offers a much safer and more reliable operation. The use of electricity eliminates the necessity for long lines of steam and air piping, which are expensive to install and maintain and with which the danger of breakdown and the difficulty of obtaining the necessary working pressures increase with every extension of the service. For these conditions electricity substitutes a simple and thoroughly flexible system of transmitting power by means of conductors

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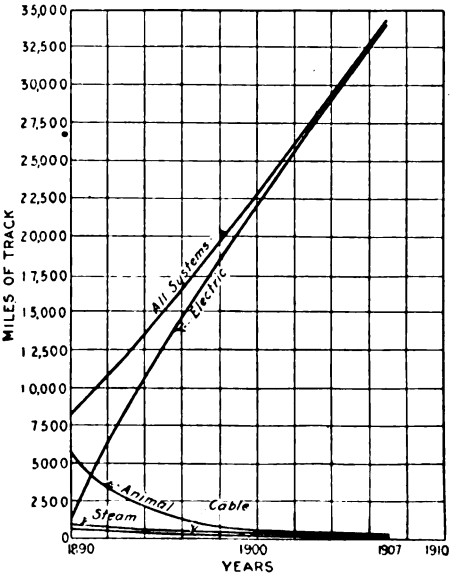
which can be easily run and rapidly extended to meet the frequent changes which are involved in the progress of the development. The flexibility of motor drive renders possible the use of portable machinery, and additions to, or changes in the location of existing machines can easily be arranged for without interfering in any way with the operation of the remainder of the equipment.

The superiority of the electric mine locomotive is now generally conceded, and is largely due to the fact that in addition to its high efficiency, mechanical strength, reliability and sim-




STREET RAILWAY SYSTEMS IN U. S.; MILES OF TRACK

plicity of control, it is the most compact form of tractor available. This is of utmost importance for underground work, where the available working room is usually very limited.

To hoisting, the electric motor affords an ideal method of application. The power is uniformly applied throughout the operating cycle as there is no reciprocating motion or intervening connection rods or cranks with their varying torque at different positions. The power demand is limited to the time during which the hoist is in actual operation, which minimizes the amount of power consumed, while on the other hand, it is

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possible to provide flywheel sets for eliminating the peak loads and equalize the load.

The above are only a few of the most important mine applications and besides these, the electric power is very extensively used for pumping, ventilation, coal cutters, drills, crushers, etc.

Electric steel refining furnaces and processes are now widely employed, and based on the number of furnaces in actual use, it may be said that the electric steel industry is now well established and of considerable importance. In this field the electric furnace has three applications. First, for the production of higher grade tool steels, etc. in competition with crucible steel; second, the refining of Bessemer or open-hearth steel for the production of large quantity products, like rails; and third, for the production of a higher grade of steel for castings. Of these the last named is attracting considerable attention at the present, the advantages being that the higher temperature obtained by the electric method of heating yields a more fluid metal, and a better separation of the gaseous and other impurities of the steel is thereby obtained. Considerable progress has also been made in the utilization of electric steel for high grade tools, while for the refining of Bessemer and open-hearth steel it has not been as rapid.

The production of pig iron from iron ore in the electric reduction furnace is still restricted and has only made progress in Sweden where high grade iron ores are plentiful and where due to the abundance of easily accessible water sites, electric power can be developed at a very low cost.

Extensive experiments and research work are being carried on for the use of the electric furnace for non-ferrous metals. This problem has, however, not advanced far commercially, although it seems as if the electric zinc furnace is approaching its final solution.

The electric welding of metals is not a new process, but in the last few years it has been successfully applied in the manufacture of many products that have heretofore been made by other methods.

The application of electricity to iron and steel plants, while already reaching large proportions, is destined to grow continuously. It began with such apparatus as cranes and pumps, where the duty was similar to that which motors were already handling elsewhere. Then the adoption of the railway motor and finally the development of the splendidly substantial mill-

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type motor brought all the auxiliary apparatus into line. Now the roll trains, lifting tables, shears, etc. are all taken care of electrically, and so satisfactorily that any other means will hardly be considered in a new mill.

The advantages of electric motor drive in a steel mill are many. Besides the economy derived from the superior efficiency of the electric motor over rolling mill engines, a great saving obviously is made in the centralization of all the power supply from a common generating station. The great overload capacity inherent in the electric motor, close and positive speed regulation, smooth and uniform torque, simplicity and reliability, are all factors of utmost importance in the selection of this system. In no other industry is absolute continuity of process such an imperative consideration. The financial loss resulting from the temporary shutdown of the main rolls, for example, is estimated at from $400 to $1000 per hour, depending upon the nature of the work involved. It is obvious that twenty-four hour service is of prime importance and that only the most efficient and absolutely dependable drive is permissible. It is for these reasons that the extensive application of electric power to steel mill work has won this enviable reputation.

The lumber industry, woodworking plants, pulp and paper mills, etc., offer a very promising field for electric power application. Experience has fully demonstrated that the electric drive very materially increases the quality and quantity of production. This is especially true for the paper mill in that each machine can be operated and each kind of paper finished at the correct speed. The factor of safety is greatly increased both to machinery and operators, while at the same time there is a marked reduction in the fire hazard, especially from open flames and hot boxes.

The application of electric motors to the driving of textile-mill machinery has been one of the most conspicuous industrial developments within the past twenty years, but still the proportion of electrically driven textile mills is considerably below what may fairly be anticipated within the next few years. While the textile industry of New England was developed before the period of electricity, the most unusual growth of the cotton-mill industry in North and South Carolina, where now by far the largest number of cotton mills will be found, has been due without question to the development of a large group of water powers, which exist on the Appalachian water-shed, and which

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lay undeveloped until their power could be economically transmitted to profitable market centers. The Southern Power Company is the most conspicuous in this respect. This system alone controls over 300,000 h.p., of which over one-half is now developed and transmitted to various industrial enterprises. There are over 1300 miles of transmission lines, and power is supplied to over 150 cotton mills, few of which existed when the system was first put in operation.

The enormous possibilities for a very extensive use of electric power in connection with farming and agricultural work are obvious when one considers that though agriculture produces about forty per cent of the total wealth of the United States, much less of its work is done by electricity than in either manufacturing or railroading, each of which represents only half as much wealth. If the twenty million horses and mules now used in farm work were displaced by mechanical power one hundred million acres of cultivated land would be released for human requirements, and it is safe to attribute the high cost of living to a very great extent to the very low efficiency of farm labor as compared to the higher efficiency in other industries whose rapid growth will continue to make even greater demands upon the farm productivity. The use of electricity on our farms is therefore sure to be greatly increased, and that this is becoming generally recognized by our central station interests is clearly demonstrated by the extensive network of transmission and distributing circuits which are being built and extended to cover the vast rural districts all over the country.

The advantages of electric power for irrigation purposes have also been clearly demonstrated by the excellent work which has been done by the United States Reclamation Service. The Salt River project in Arizona, when completed, will irrigate no less than 270,000 acres of arid lands and the Minihaha project in Southern Idaho will be capable of furnishing irrigation for about 50,000 acres, while there are numerous other such undertakings in the West.

The use of electricity for stimulating and increasing the crops has been given considerable study but the results so far obtained have not been of very great importance, although the future may bring forth new discoveries which may lead to commercial possibilities along these lines.

Very closely connected with the farming industry is the fertilizer industry. Due to the permanent drain of nitrogen

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from the soil the farmer must find sources from which it can be abundantly and readily obtained. Nature herself has furnished the greatest available sources, and various manufacturing by-products have been found of value as fertilizers. The greatest of all nitrogen reservoirs—the atmosphere—although known always, has, however, only recently been made available through the efforts of man. There are several commercial processes for the electrical fixation of the atmospheric nitrogen, chief among which are those used by the vast industries in Norway. These started about eight years ago and the industry is now well established in that country, about 300,000 h.p. being utilized for this purpose.

To cover all the different fields to which electric power has been and will in the future be extensively applied, is impossible. Besides the above mentioned industries there is every assurance that great progress will be made in the electrification of our trunk lines, in the handling of freight at railroad terminals, wharfs and docks, for the propulsion of vehicles and for various purposes in the automobile industry. Extensive use will also be made of electric power in marine and naval work, and its application and usefulness in connection with ship canals is well illustrated by the Panama Canal, the operation of which will require over fifteen hundred electric motors. These will be most readily operated from centrally located stations, and by means of automatic features and interlocking devices a simplicity and reliability in the operation is obtained, that could not be equaled by any other system.

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DISCUSSION ON "THE DIELECTRIC STRENGTH OF THIN INSULATING MATERIALS" (FARMER), NEW YORK, DECEMBER 12, 1913. (SEE PROCEEDINGS FOR DECEMBER, 1913.)

*(Subject to final revision for the Transactions.)*

**F. W. Peek, Jr:** Three types of insulation are in general use—gaseous, liquid, and solid. The mechanism of breakdown differs in many respects in the three types. Any insulation, under given conditions, ruptures at a given point when the dielectric flux density at that point exceeds some definite value. The total dielectric flux depends upon the capacity and the electromotive force; that is, upon the size and spacing of conductors and the voltage between them. The flux density at various points will also be different, depending upon the configuration of electrode. The flux density at any point is proportional to the gradient at that point. The strength of insulation, therefore, may also be expressed in terms of the *gradient measured at the point where rupture occurs*. The voltage required to rupture insulation, divided by its thickness, is not a measure of the insulation strength. It is the average gradient. The maximum gradient where rupture starts is much higher. For instance, take two pairs of spheres, one pair a half-centimeter in diameter, spaced one cm. apart, and the other pair two cm. in diameter, spaced one cm. apart. Apply a voltage of 100 kv. across pair No. 1. The gradient is maximum at the surface and is by calculation $\frac{de}{dx} = 270 \frac{\text{kv.}}{\text{cm.}}$. The average gradient $\frac{e}{x} = \frac{100}{1} \frac{\text{kv.}}{\text{cm.}}$. On pair No. 2, 100 kilovolts gives

$$\frac{de}{dx} = 135 \frac{\text{kv.}}{\text{cm.}}; \quad \frac{e}{x} = 100 \frac{\text{kv.}}{\text{cm.}}$$

Thus for the same voltage and spacing the actual stress is quite different, depending upon the curvature.

If 20-cm. spheres are taken, under the above conditions $\frac{de}{dx} = 103$ and $\frac{e}{x} = 100$. Thus with large radius the average gradients and $\frac{de}{dx}$ are approximately equal. This is the reason that in any investigation (other than commercial testing) made to determine the strength of insulation, some electrode is taken in which the dielectric flux density and gradient at various points can be calculated—that is, spheres, parallel wires, or a wire in a cylinder. These may be arranged so that the break is local, as corona in air on two parallel wires at large spacings. The break starts at the surface because the flux density is a maximum there. The conducting corona extends out approximately to a point where the flux density is below the breakdown density. Only when the surfaces are close

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together does a complete spark-over take place before corona forms.

Let us now consider briefly the mechanism of breakdown of three types of insulation.

*Air.* Air has a greater apparent strength around small conductors than large ones, as for instance, spheres or wires. The explanation apparently is that air has a constant strength of $30\ \frac{\text{kv.}}{\text{cm.}}$; rupture, however, does not occur when this gradient is reached at the conductor surface, but only when this gradient is reached at a finite distance from the conductor and when the gradient at the surface is therefore higher. Energy is necessary to rupture insulation. The rupturing energy is stored in this space between the conductor surface where the gradient is high and a finite distance away where the gradient is 30 kv./cm. This distance may be called the energy storage distance, or it may be considered as the distance required to reach ionic saturation by successive collisions between the conductor surface and where the gradient is $30\ \frac{\text{kv.}}{\text{cm.}}$, the " accelerating distance".

This distance is $0.301\ \sqrt{r}$ cm. for wires, and $0.27\ \sqrt{R}$ cm. for spheres. If the conductors are placed closer together than the free energy storage or accelerating distance the apparent strength increases in order that sufficient energy may be stored in the limited space.[1] Although the real strength of air, or the gradient required to bring the ions up to sufficient velocity to produce other ions by collision, is 30 kv. per cm. between parallel planes, with limited energy distance, that is, thin films, gradients as high as $250\ \frac{\text{kv.}}{\text{cm.}}$ are required to cause rupture. There is very little loss in air until after rupture, as brush discharge or corona, occurs. For this reason air may be stressed to within a few per cent of breakdown voltage without loss and consequent heating and weakening. Air is uniform and homogeneous and therefore free from " weak spots". The curves given in Fig. 6 of Mr. Farmer's paper are, on account of the characteristics stated above, exactly what would be expected. The ordinate does not represent the dielectric strength, but $\frac{e}{x}$, the average gradient of rupture. The dielectric strength would be represented by $\frac{de}{dx}$. Take for example the curve at

1. This is fully discussed in the following papers by F. W. Peek, Jr.: *The Law of Corona and the Dielectric Strength of Air-I*, TRANS. A.I.E.E. 1911, Vol. XXX, Part III, p. 1889; *The Law of Corona-II*, TRANS. A.I.E.E. 1912, Vol. XXXI, Part I, p. 1051; *The Law of Corona-III*, PROCEEDINGS A.I.E.E., June, 1913, p. 1335; and " High-Voltage Engineering," in the *Journal* of the Franklin Institute, December, 1913, (No. 1056) page 611.

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210-mil spacing. Fig. 1 of this discussion gives curves plotted from data taken from *The Law of Corona-III*, for 0.508-cm. (200-mil) spacing between spheres. Plotted with $\frac{e}{x}$ this gives a curve exactly similar to Mr. Farmer's in Fig. 6. Plotted with $\frac{de}{dx}$, the actual gradient at the surface where breakdown occurs, the curve increases with decreasing diameter of sphere, due to the varying energy distance with varying diameter of sphere. As the radius of the spheres increases the average gradient curve $\frac{e}{x}$ and the surface gradient curve $\frac{de}{dx}$ come together, because as the radius becomes large compared with the spacing the flux becomes more nearly uniform.

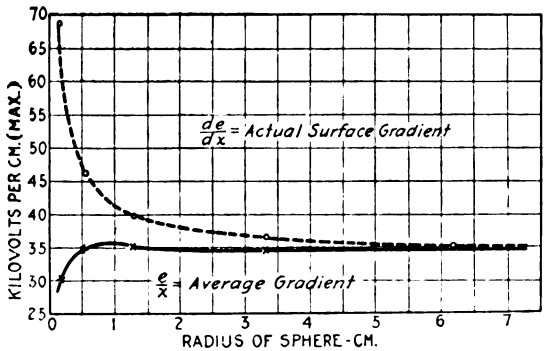


FIG. 1—SPARK-OVER OF SPHERES IN AIR. SPACING = 5.08 CM. (200 MILS.)

*Oil.* The mechanism of breakdown of pure oil is very similar to that of air and follows the same laws.[2] The constants are, however, different. The energy distance and therefore the apparent strength is much higher. With limited energy distance strengths as high as a million volts per cm. have been reached with electrodes which gave an apparent strength of $100\ \frac{\text{kv.}}{\text{cm.}}$ when the energy distance was not limited.

*Solid Insulation.* Like air and oil, solid insulations require energy to cause rupture and therefore have a greater apparent strength for small conductors and for small spacings or thin films. If the curves in Fig. 1 in Mr. Farmer's paper were plotted with the true gradient $\frac{de}{dx}$ where rupture starts, and not $\frac{e}{x}$,

2. "High-Voltage Engineering," Franklin Institute *Journal*, loc. cit.

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the gradient would increase with decreasing electrode and not show the maximum hump. The curve as plotted does not express the dielectric strength. If this curve were taken at a larger spacing and plotted with $\frac{e}{x}$ the hump would occur at a larger size of electrode. There are conditions where the hump, due to varying energy distance with radius, might actually occur when plotted with the actual gradient. This curve is also affected by the "weak spots", otherwise the curve would be parallel to the axis when the "flat disks" are used. These disks have about equal curvature on the edge, and thus equal effect due to flux concentration. $\frac{e}{x}$ may then be used for comparing strength. This part of the curve practically follows the probability curve.

| | |
|---|---|
| 10 | 15 |
| 18 | 20 |
| 10 | 12 |

FIG. 2

For example, suppose Fig. 2 herewith, represents a piece of solid insulation one mil thick and *sufficiently large to cover every condition of "weak spot"*. Divide this into six equal squares, each of area *a*. The strength is marked on the various areas. Assume that an electrode giving no edge effect is used. With electrode of area *a*, six tests are required to go over the whole piece. With electrodes of area 2*a* three tests are required, with area 3*a* two tests, and with area 6*a* only one test. The following results may be obtained:

| Area of electrode | No. of punctures | Total area covered | Volts per mil | | |
|---|---|---|---|---|---|
| | | | max. | min. | average |
| a | 6 | 6a | 20 | 10 | 14 |
| 2a | 3 | 6a | 18 | 10 | 13 |
| 3a | 2 | 6a | 12 | 10 | 11 |
| 6a | 1 | 6a | 10 | 10 | 10 |

The results are somewhat similar to the lower points of the curve in Mr. Farmer's paper. By the method described in the paper, however, the same number of punctures is taken for each size of electrode. Thus for the large electrodes much more insulation is tested than for the small electrodes, and the minimum should therefore be much lower for the large electrodes. In the example I have given, the number of tests is taken so that the total area covered is the same for all electrodes. Thus where edge effect exists it would be more rational to make the circumference covered equal.

With laminated insulation, as in cables, this effect of weak spots should not be so great, as they are not likely to line up in the separate layers.

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The curves obtained are therefore probability curves modified by flux distribution (because they are not plotted in terms of maximum flux density), and energy distance.

While loss in air and pure oil is a phenomenon after breakdown occurs, in solid insulation loss occurs as soon as voltage is applied. This heats the insulation and weakens it. It is for this reason generally impossible to hold more than 25 per cent of the "instantaneous" puncture voltage indefinitely. For instance, on a given insulation, if the voltage is brought up rapidly or "instantaneously" 100 kv. may be required to cause rupture; 75 kv. may be applied for one minute before rupture occurs; 50 kv. may be applied for four minutes, and 30 kv. indefinitely. Very high voltages of steep wave front, or of exceedingly short duration, may be applied without apparent effect, but which, upon a number of applications, cause puncture.

The mechanism of breakdown in solid insulation is quite complicated and greatly affected by occluded air and moisture. If a local breakdown occurs, local charring takes place. This concentrates the flux and the break is extended by steps indefinitely. Breakdown often occurs in this way by a concentration of the flux, independent of true dielectric strength, as the result of moisture, which places extra stress at local points.

Although with flat plates the exact gradient cannot be calculated, they are sufficient for most practical purposes in commercial test. The radius of the plate and also of the edge should be specified. The test should also, probably, be made under oil. The method of applying voltage should be specified, as well as material and weight of disk, and method of drying material, etc. A great deal depends upon radiation and heat conduction. After all, the "instantaneous" breakdown tests, just discussed, are of little commerical use unless an endurance test is added—that is, as is generally done, by starting at a given percentage of the instantaneous voltage and increasing by a given percentage at given time intervals until puncture occurs. We will be greatly helped in commercial testing when means of measuring small energy losses are simplified and perfected. In this way the presence of moisture is quickly shown.

**Phillips Thomas:** Mr. Farmer's paper brings out many points and adds one more link to the chain of evidence, showing the necessity, when giving figures for dielectric strength, of including pretty exact information on the method used in making the tests.

The results at which he has arrived agree in general with those found by the writer and by others for electrode diameters up to $\frac{1}{2}$ in. (12.7 mm.).

As stated in this paper, the law of probability does not seem to apply below $\frac{1}{4}$ in. (6.35 mm.) diameter of electrodes, and from the nature of the material tested it seems certain that the limiting size of electrode which would always cover the weakest

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spot will occur long before 15 in. (38 cm.) is reached. Since the charging current through the dielectric at a given voltage varies inversely as the dielectric thickness and varies directly as the electrode area, any distortion due to this current will react directly on the values found.

In testing various sizes of condensers for breakdown strength, we use an outfit very similar to that described in this paper and have found it necessary to parallel the tested condenser with one of much larger capacity so that the distortion and regulation at a given voltage will not depend upon the capacity of the piece being tested. We have been forced also to measure the breakdown voltage directly at the electrodes, in order to reach comparative results.

The paper states that the voltage reading was checked at intervals by connecting an electrostatic voltmeter directly across the high-tension terminals. Such a check will detect any capacity regulation if made while the test piece is connected, but will not give any information as to distortion. This distortion and regulation will be different for each area and thickness tested and is certain to give misleading results, unless either its presence or its effect is eliminated in some way.

**R. P. Jackson:** This paper by Mr. Farmer gives some data that are in a way quite surprising and show strongly the importance of having standardized methods of testing insulation materials.

In general, it is my opinion that the lower valued results obtained by Mr. Farmer come nearer the truth in the form in which it is desirable to know it, for the reason that the large area electrodes more nearly duplicate the conditions under which insulation operates and is subject to stress. For that reason the lower valued results obtained with the large area disks apparently give a better guide for the use of the material, and at least as good a guide as to the quality of various grades of similar material.

Different explanations can be offered as to why the results vary so much with the different sizes of electrodes, and the time not being sufficient to duplicate any of the tests, one cannot more than conjecture as to the actual cause of the variation. Varying sizes of electrodes with very thin insulation will, of course, vary the static capacity of the test, and if the supply transformer is small, may cause a rise of voltage at least when the supplied voltage is near its maximum value and the insulation under greatest stress. The condition of capacity and corona or static fringe around the electrodes is liable to cause surges and oscillations which would tend to produce puncture at lower apparent values. Thin air pockets between the electrodes and the insulating material also become sources of corona and therefore heat which might vary with the size of electrodes, especially if the insulating material and the electrodes were not exact plane surfaces and sufficient pressure were not brought to bear to bring

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the two surfaces into contact. Another source of variation has been betrayed by similar tests in which thin material failed when the electrodes were of tinfoil of considerable area, and failed at a much lower value than when the electrodes were of small area and of brass pieces of considerable mass. Such tests, however, were of some little duration and the difference in such a case was probably due to the fact that with the tinfoil the heat from insulation losses was not absorbed and the temperature of the insulation rose with corresponding increase of loss until failure occurred. In the case where the massive brass electrodes of small area were used on the same insulation, the mass of the brass and its radiation surface were sufficient to absorb the watt loss in the insulation and kept the temperature moderate and prevented the insulation reaching the unstable condition where the watt loss increased the temperature, and the rising temperature increased the watt loss indefinitely to failure without increase of voltage.

It is the writer's experience that instantaneous puncture voltage tests or tests of very short duration are of rather limited value in furnishing data for judging the use to which the insulation can be put, and only a test lasting long enough to give the approximate ultimate breakdown value with long continued application of the voltage will give the information desired.

**C. E. Skinner:** As I began insulation work rather early in the art, I think it might not be out of place to review very briefly some of the steps which have been taken in that work. The regular testing of dielectrics and the dielectric tests of apparatus began, with the company with which I am connected, early in the year 1890. At that time we had little or no information to guide us, either as to what dielectric stress meant or anything concerning the effect of the shape of terminals, and 10,000 volts was an almost unheard-of voltage to work with. During the five years that followed, the dielectric testing of materials covered practically every known material and many that probably should have been unknown, and tests of many things that proved not to be dielectrics.

During that early period I think the insulation engineer was one of the most disliked and maligned individuals in the whole engineering profession. The designer calculated to a nicety the copper and the iron, and space used for insulation he considered lost. Furthermore, the more insulation put on, the hotter the machine would get, because the insulating material was also heat insulating material. It was, therefore a constant struggle between the insulation man and those responsible for the rest of the design.

In spite of the more than twenty years of work that has been regularly done since dielectric testing came into vogue as a regular test in practically all large manufacturing establishments, the present state of the art is most chaotic.

I hope that this paper will culminate in a better set of testing specifications. We have heard in the last two days in our

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committee meetings a good deal about coöperation. The American Society for Testing Materials has a committee whose duty it is supposed to be to formulate specifications for testing insulating materials. It appears to me that it is more the function of that Society to formulate a detail specification as to methods of testing than it is of this Institute, but that Society cannot do this work without the co-operation of the Institute and it is probably the function of the Institute to formulate something as to the electrical end of this work, I hope that this can be done. I know that a certain amount of work has been done in trying to arrive at a test which will give what we might call the endurance of insulation, which is really the thing that we want to know when we design our apparatus. I agree with Mr. Jackson and others that the instantaneous value is of comparatively little worth in design work. I learned very early to use a very large factor of ignorance in applying the results of my instantaneous values, because I found for example, that when thin sheets of insulating material went into a dynamo, and passed through manufacturing steps, the dynamo, as a whole, would have nothing to compare in dielectric strength with the values per mil which might be obtained on the thin sheets. There are many reasons for this lower value outside of the strength of the material itself; the workmen in the shop may contribute something to lowering the dielectric strength of the materials given them to put on the machine.

I feel that the conclusions arrived at in the paper might possibly be subject to some modification if the tests were made under different circumstances, such as a change in the testing transformer, a change in the method of applying the voltage, a change in the pressure, etc.

I think it would hardly be right in this meeting not to mention the classical work on dielectrics done by Rayner in the National Physical Laboratory. That work followed and completed, for thin materials, a mere start which was made a number of years ago by Mr. Miles Walker and myself, and published in the Institute TRANSACTIONS[3] for the year 1902. Mr. Rayner carried it to a great length, and by measuring the dielectric losses was able to predict when his insulating material was going to break down.

I feel that the future work along this line will have more to do with the study of the power factor, and the study of the dielectric losses, and the study of the endurance of the insulation under continued stress, and I hope that before another year the Institute may be able to adopt the electrical end of a scheme for the endurance test, and possibly for the loss test of insulating materials. I think this paper will do much to bring to us the importance of a standardization of methods, and in such standardization we must necessarily pay attention to every detail in order to arrive at results which would be in any way comparative when made in different laboratories and when made with different materials prepared under different conditions.

3. Vol. XIX, page 1047

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**H. W. Fisher:** When we first commenced to use varnished cloth as an insulation for cables, it was necessary to design an apparatus by means of which we could determine the insulation resistance, the electrostatic capacity, power factor or dielectric loss and dielectric strength of different kinds of cloth. In order to accomplish this, the following apparatus was designed.

Two circular disks were made with a circular groove in each, the inside diameter of this groove being one foot (30.5 cm.). Into these grooves were fitted high-grade rubber gaskets, the ends of each of which almost came together at the top. One disk was mounted rigidly in a vertical position; the other disk was provided with insulators and on an auxiliary frame were four horizontal screws, the ends of which were inserted into insulated posts on diametrically opposite parts of the movable disk. By means of these screws the movable disk could be tightly clamped against the fixed disk so that the rubber gaskets of each would be directly opposite each other. The varnished cloth to be tested was placed between the disks, and pressure applied so as to make a tight joint between the rubber gaskets and the varnished cloth. Attached to the stand of the apparatus was an iron box containing mercury and from the box there were two rubber tubes which connected with a suitable valve at the bottom of each disk. By opening the valves and raising the mercury box, mercury was allowed to flow on each side of the varnished cloth until it reached the small aperture at the top of the rubber disks. Then the valves were closed, the mercury box was lowered to its normal position on the base of the apparatus and the rubber tube attached to the insulated disk was removed, after which the tests mentioned above were made, ending with the breakdown voltage test.

By means of this apparatus, samples of varnished cloth of different manufacture were tested and the power factors were found to vary approximately from four or five per cent to twenty per cent. By making various tests and profiting thereby, the quality of the varnished cloth was very much improved.

It was next necessary to design another type of apparatus for testing cloth in strip form, the way it occurs mostly in the trade. In order to be able to test narrow strips without flashovers around the edges of the strips, the following plan was devised. A strip of brass about $\frac{1}{4}$ in. (6.35 mm.) wide was placed on a wooden board so that one or two thicknesses of varnished cloth could be put underneath the brass. The brass strip formed the lower electrode of the apparatus. The upper electrode consisted of a copper strip about $\frac{1}{8}$ in. (3.2 mm.) wide, mounted on insulated arms so that it could be swung to one side when not in use. The general plan is to put vaseline over the varnished cloth which is placed underneath the lower electrode so that the narrow strip of varnished cloth to be tested

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can be placed centrally over the lower electrode and parallel with it and the edges of the cloth pressed firmly into the coating of vaseline, after which the upper electrode is turned over so as to drop in position above the lower electrode. In this way, puncture tests of varnished cloth can be made without any danger of flash-overs around the edges of the strip of cloth tested.

In the testing of cloth with electrodes of different lengths or diameters, care must be taken to proportion the number of tests made to the areas tested. In other words, if a test is made to determine the relation between tests with disks 1 in. (25.4 mm.) in diameter and with disks 20 in. (508 mm.) in diameter, 400 tests should be made with the 1-in. diameter disk, to one test of the 20-in. disk, and the minimum of the 400 tests taken as the tests which ought to correspond to the one test on the 20-in. disk. Bearing this in mind, we made a number of tests which do not show at all the difference indicated by Mr. Farmer's figures. I think that he did not make enough tests of the larger electrodes to get a fair comparison. In order to make a check with a view to determining if the above theory was not correct, we took a roll of cloth and made forty tests consisting of five groups of eight, with electrodes 1 in. (25.4 mm.) long, and then got the average of the minima of these. Next we took the average of ten tests made with electrodes 8 in. (203 mm.) long, and the two sets of measurements agreed within two per cent.

For the same reason just explained, a short length of cable will almost always withstand a higher voltage test than a long length of the same cable.

The old Underwriters' rule was to apply a test of 3000 volts per 1/64 in. (0.397 mm.) of insulation on a one-foot (30.5-cm.) sample. Wire insulated with almost any kind of rubber would withstand that test on a one-foot sample, whereas a coil of wire would break down under the test of 3000 volts per 1/64 in.

**M. E. Tressler:** Last January when making some very similar tests on yellow varnished cloth I obtained practically the same shaped curves as Mr. Farmer has with various sizes of electrodes from 1 mm. to 100 mm. in diameter with approximately square edges.

A curve showing this variation in disruptive voltage with diameter of electrode for 10 layers of yellow varnished cloth tested under oil at approximately 25 deg. cent. was published last winter[4]. At the same time tests were made on various numbers of layers from 1 to 20 and with electrodes whose edges were rounded to different radii from 0 to 10 mm.

My results do not show such a decided difference between the disruptive voltages with small and large electrodes as do Mr. Farmer's. The maximum disruptive voltage was 1100 volts per mil with a 5-mm. electrode and 810 volts per mil with the 100-mm. electrode.

4. *General Electric Review* March, 1913—Tressler.

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This total decrease is about 26 per cent, of which about 20 per cent took place between the 5-mm. and the 20-mm. electrodes, indicating that tests on thin insulating materials could be made with any convenient size of electrodes from 25 to 100 mm. in diameter and practically the same results would be obtained with a given material.

With greater thicknesses of insulation up to 240 mils, the variation of disruptive voltage with the size of terminal decreases, until at 240 mils there is no difference between the disruptive voltage with 5-mm. and 100-mm. electrodes. However, all of these tests were made by increasing the voltage steadily until breakdown occurred, *i.e*, the voltage was on from 6 to 12 seconds for Mr. Farmer's tests and from 4 to 8 seconds for mine. This is not a sufficient length of time to allow the

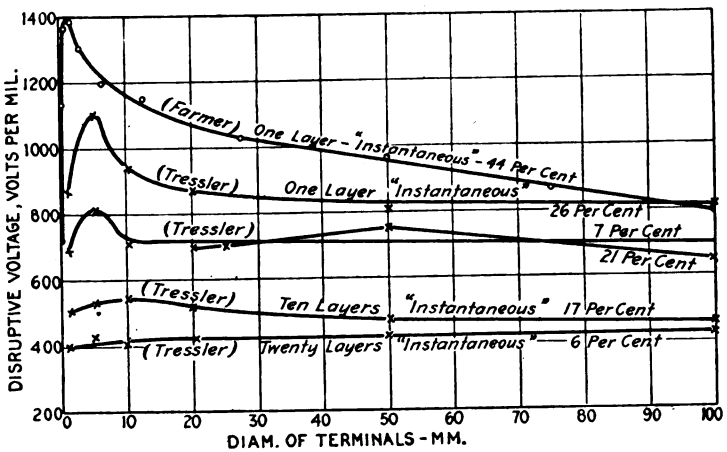


FIG. 3

insulation to be affected by the heat from the energy loss due to the alternating potential.

It would be a much better indication of the disruptive voltage of an insulation under working conditions, if " one-minute " tests were made, *i.e.*, use 50 per cent of the " instantaneous " disruptive voltage as a start for the " one-minute " test and increase by 10 per cent steps each minute thereafter until breakdown occurs.

In general the " one-minute " test will give lower disruptive voltage than the instantaneous test. Sometimes the disruptive voltage increases with increase of temperature and hence we would expect that the " one-minute " test would be equal to or higher than the " instantaneous " test.

If we use the " one-minute " test in finding the effect of terminals of different sizes we will see there is much less dif-

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ference between the disruptive voltage with 1-mm. terminals and 100-mm. terminals for any thickness of insulation.

I agree with Mr. Farmer that we are very much in need of standard specifications for the testing of insulating materials, and would recommend, briefly, the following:

1. "One-hour" tests where possible, the "one-minute" puncture voltage being used to indicate the starting voltage for the "hour" test.

2. For testing solid insulations: flat disk electrodes 10 cm. in diameter with practically square edges and insulated on the sides to prevent corona and arcing.

For testing liquid insulations: flat disk electrodes 25 mm. in diameter with practically square edges and spaced with faces parallel and 2.5 mm. apart.

3. All tests of solid insulation should be made under oil when possible and with a pressure of 100 g. per sq. cm. applied by the terminal to the insulation.

4. Two temperatures of test should be considered standard; one at 25 deg. cent. and the other at the highest "hot spot" temperature allowed on the given insulation to be tested.

5. The insulation for test should be 2.5 mm. thick or as near thereto as possible.

With these tests complete on a given insulation we would be able to judge very closely whether the insulation in question was suitable for the place and work required of it.

A better indication of the value of an insulation for high or moderate voltages would be to measure the thermal conductivity at different temperatures and the energy loss at various voltages and temperatures.

Then if the insulation had a large energy loss and low thermal conductivity we would know that it would not be of much use as a high-voltage insulation, whereas if the energy loss were small and the thermal conductivity high we could be sure of a very good insulation, so far as electrical properties are concerned.

Of course we must consider the kind of insulation being used, whether organic or inorganic, how treated and at what maximum temperature it could be run continuously.

In reply to one point brought up by Mr. Thomas, the distortion of the voltage wave across the insulation, I would say that several years ago when testing a piece of insulation of comparatively high permittivity between 25-cm. disk terminals at 50,000 volts, Mr. A. B. Hendricks took an oscillogram of the current wave in the insulation and found it to be practically a sine wave. If there had been any appreciable harmonics in the high-potential voltage wave they would have been magnified by the capacity, in the current wave; hence we may readily assume that, since the current was a sine wave, the voltage also was a sine wave.

**E. B. Rosa:** I would like to emphasize what has been emphasized already by several of the speakers, and that is the

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advantage of having something like standard methods for making insulation tests, and also the advantage of making energy measurements in addition to the breakdown measurements. The measurement of the power factor of the current flowing through such a dielectric reveals wonderful differences, much greater than one would expect. A plate of mica will have a very small power factor, its angle corresponding to the power factor being as small as one minute of arc. That is, the angle by which the current differs from a 90-deg. advance of the e.m.f. is as small as a minute of arc, or smaller. As Mr. Fisher says, in some materials it may be 20 deg., may range anywhere from a minute, or less, to many degrees, so that the heating effect and the energy expended may vary through a range of a thousand to one, and, naturally, if the heating effect is large, the dielectric strength will sooner or later be very much affected.

The work of Dr. C. Kingbrunner, at the Technological School at Manchester, about eight years ago, was very carefully done, and is quite an extended piece of investigation. He stated that he found the values of the dielectric strength to vary with the pressure, and as the pressure was decreased gradually, it finally became constant. He gives a curve showing the relation between the pressure and the measured dielectric strength, using a pressure of 500 g. per sq. cm., beyond which the value was constant. He also stated that electrodes of greater diameters than two cm. vary appreciably. He used a diameter of four cm. in order to be sure to have them large enough. These results are different from those cited in the paper, and illustrate the need of taking account of previous work and also of having all the work that has been apparently carefully done, and has been published, reviewed by some co-ordinating agency in order that the best results may be reduced for all this work.

I was very much interested in what Mr. Skinner said about coöperation in solving such a difficult problem, or, at least, making progress with such an important and difficult problem as this, and as he is so thoroughly convinced of the need of it, it is encouraging, because he is in a fortunate position to bring about such coöperation, as chairman of the committee of the American Society for Testing Materials.

**Clayton H. Sharp:** The facts in Mr. Farmer's paper, and these other data that have been presented tonight, show more than anything else the elusive character of the problem of testing insulation. It is a case of " now you get it " and " now you don't get it ", and just why these curious effects occur is, of course, a matter of very great importance. I do not think that the phenomena which occur are quite so easily explained as one of the speakers tonight would have us believe. Mr. Farmer's results alone show that the matter is more complicated. The question of averages undoubtedly enters, but there is something more than that to it.

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Here we have one of the most important elements which enters into the construction of all electrical machinery and apparatus, and it is quite evident that we are unfamiliar with a good many of the fundamental and underlying attributes of this material. It is, therefore, very necessry that further researches of the character of these which Mr. Farmer has made, and of more extensive scope, should be carried on. In the meantime, for the purpose of the practical testing of apparatus, it is of very great importance that some standard specification should be prepared and should be followed.

**John B. Taylor:** We have here a paper dealing with stresses in insulating mediums, without formulas or mathematical symbols, and yet perhaps of more practical application than some of the papers in the last few years on corona and the distribution of stresses around points, spheres, and other shapes. The curves and results discussed in the paper are quite different from those the theories would seem to lead to. As the paper offers no explanation of these results, it is to be regretted that it is not more complete in a few respects so that the conclusions can be either accepted or doubted for good reason.

There seem to be three factors which may account for the lower breakdown strength per mil as the size of the surface covered is increased. In the first place, if the testing transformer is small, the increase in capacity would tend to raise the voltage on the test specimen without raising it by the same amount on the low-tension voltmeter. Second, as previously brought out, when dealing with a larger sample, by the law of chances we ought to find some weak spots. Third, with the larger sample there is less chance for the radiation of heat. Since all three of these factors work in the same direction, a combination of them may account for the results given.

Mr. Tressler has given some information which corroborates, although not to the same degree, the general character of the results. My own first impression was that the heating was the most likely factor, but this impression does not hold after seeing that the voltage has been brought up at the rate of 1000 or 1200 volts per second, and as the specimens are only 10 or 12 mils thick, the whole test is over in eight or ten seconds. That leads me to ask how it is possible to establish the figures of volts per mil to some four or five parts in a thousand, when the voltage is changing so rapidly.

Also, I would like to ask if the failures in general occur at the edge of the different disks, or whether they are just as likely to occur in the middle.

It would seem desirable to give, in tabulations like these, the average deviation of the results from the mean result. The maximum and mean are given, but the average deviation gives a better idea of the concordance of the observations.

I have a suggestion to make. Many tests of this sort might be made with direct current, which would eliminate some of the

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uncertain factors when dealing with alternating current. The heating factor would be eliminated, and also the question of voltage ratio and capacity factor.

**A. E. Kennelly:** The subject matter of the paper appears upon its face to be very simple. We have here flat electrodes, and except when the electrodes are very small—half a centimeter or less in diameter, we can hardly avoid the conclusion that the stress which ought to be imposed in a uniform dielectric between such flat electrodes is substantially uniform over the entire surface, and we also all believe, I think, that uniform homogeneous material breaks down electrically at the same electrostatic flux density, which means when the maximum local gradient of potential attains one and the same breakdown value.

Starting from this premise, where we would naturally suppose that for the same thickness of material, like varnished cambric the breakdown stress should be the same for different sizes of the different diameter of electrodes, from 0.5 cm. to 10 cm., or more, the values given in the paper show that they are not the same. How are we to reconcile these inconsistencies?

If we assume that there is air pocketed in thin films somewhere, then we have the three dielectrics, air film, varnish film, and the cambric, and these three layers are capable of being associated in various thicknesses which might give rise to variations of electric flux-density and gradient.

It has been pointed out by several of the speakers that one of the conditions involved is the relative chance of including weak spots; but, as has been pointed out by the author of the paper, if that were the case, we should certainly expect what may be called the probable error to be much greater for the little electrodes than for the big electrodes, and if the probable error were greater, the difference between the maximum and minimum voltages of the ten samples would certainly differ very materially, whereas actually, an inspection of the tests indicates that substantially there is the same difference between maximum and minimum voltages in the ten tests on each particular size of electrode. We cannot find an explanation here in the different probabilities of including weak spots.

Since this remarkable variation of dielectric strength with electrode diameter does not seem to be explained satisfactorily, it becomes the more important to standardize the dimensions of test electrodes until the matter has been cleared up.

**H. M. Hobart:** The subject which is uppermost in my mind at the present time is the need of establishing some relation between the rate of aging of insulating material and the temperature to which it is subjected. From experience with apparatus in service, we have a good idea of this relation up to a little over 100 deg. cent., but we want to consider how far we can go in the direction of higher temperatures with conservatism. As for the range between 110 deg. cent. and 200 deg. cent., the data at our disposal are very meager indeed. The meagerness of our

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data relating to aging is rather discouraging. One cannot afford to wait several years for the results of aging tests before employing attractive methods of insulating machines. Nevertheless, the sooner we embark upon elaborate aging tests the sooner we shall have the results commercially available. If a certain material ages imperceptibly at 100 deg. cent., it may age with decided rapidity at 200 deg. cent. If we were to maintain a number of samples at a temperature of 200 deg. cent. the results obtained in a week or a month might be very instructive. We could bake one set of samples at 180 deg., another at 160 deg., another at 140 deg., and another at 120 deg., and take out samples periodically from the ovens. From the results we should be able to establish a curve for that particular insulating material which would give a clue to what we could do with that material in insulating commercial machines. When used in the construction of slot insulation, it might not conform closely to the results which would be obtained by samples tested in the laboratory, but the results would, nevertheless, be indicative.

There is a matter of considerable importance to which I should like to allude. In a paper recently read before the Institution of Electrical Engineers of Great Britain by Mr. S. Eversched, a very interesting footnote appears in which the author states: "The flash test as applied to some costly piece of electrical apparatus must have been inspired originally by something akin to the heroism of the savage." Ever since the time to which Mr. Skinner alludes we have been making tests on electrical machinery not very unlike flash tests. Such tests are still made and are jeopardizing the subsequent life of the machines. The machine may survive the test, so far as we can perceive, but we do not know that we have not caused some serious damage to the machine which will make it of less service during its working life.

**W. I. Middleton:** In the breakdown tests of cambric cloth insulation, I have used 12-in. (30.48-cm.) electrodes rather than smaller ones, believing the results would be nearer the average breakdown value of the cloth.

My experience with the large and small electrodes has been very similar to that of Mr. Farmer. Between the large and small electrodes, 12-in. (30.48-cm.) and 1-in. (2.54-cm.), I have found an average difference of about 50 per cent increase with the smaller ones. Other investigators have found similar results when investigating along other lines. Mr. Fisher says the short length of cable will stand more voltage than the long length, and my own experiences with the short samples of cables have proved this to be so. Experiments with corona on bare wires have shown that the corona starts at a lower voltage on long lengths than on shorter ones. There is evidently some fundamental law underlying all of these results, although the experiments have been along lines so very different.

In regard to the probability law, we have experimented with

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different insulating materials, trying to find one that would give consistent results, and have found none that was as good as air, the oil breakdowns being very irregular. The breakdown of air about the wire, as regards long and short lengths, is so similar to that of other insulations that it would appear to eliminate the law of probability, as we can hardly say that there are weak places in the air.

The chances of wave distortion with any samples of cambric, even as large as 1 sq. ft. (0.0929 sq. m.), seem to be very slight, as the charging current would be very small; this is quite possible where the charging current is considerable, as with long lengths of cables.

The instantaneous breakdown has many advantages in this class of work, if properly applied, as it allows a great many samples to be handled in a short time and eliminates the heating effect, which is one of the most difficult elements to analyze in work of this kind.

I believe we should have a standard size of electrode for this class of work so that the results of tests made by different investigators may be more readily compared, having this large element of doubt as to size of electrode removed.

**F. M. Farmer:** As to the matter of weak spots—the weak point theory seems to stick with a good many, even though Dr. Kennelly has pretty well covered it. This was pretty thoroughly discussed in the paper. Suffice it to say that it is not at all to be expected that the curves, each point on which is made up of ten tests, would all be smooth and all follow the same general shape. Furthermore, the shape is similar to that obtained for oil where there is no question of weak spots.

The possible effect of distortion with the large electrodes has been mentioned. We went into the matter pretty carefully, and could find absolutely no distortion of the wave with specimens up to 15 in. (38 cm.) in diameter and potentials up to 15,000 or 16,000 volts. A 10-kv-a. transformer was used.

As to the matter of heating, I do not think there can be very much in that as an explanation of these results, because the tests were of such short duration—only a few seconds. From a commercial standpoint the heating should undoubtedly be taken into account. If we want to get at the dielectric strength of the material under operating conditions undoubtedly the temperature has got to be taken into consideration, as also have pressure, and various other things. The point of this paper was simply to call attention to one of the variables and how much it does vary. Each of us is in the habit of making these tests along certain lines, and each has established his own standard electrodes, but it is well to know at least in a general way what the effect of using other electrodes might have been. It was also hoped to show the desirability of standardizing one size, for one size is as good as another because the results are quite empirical,—each designer must apply his own factor of safety.

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We have standardized specimens for testing steel but the designer does not think of using the steel in his structure up to the values given in the test. He allows a factor of safety according to the conditions.

Specifications for insulating cloth should be prepared with a view to enabling us not only to make the tests quickly and cheaply on small samples, but so that everybody will understand what they mean. Then let each individual apply his own factor of safety to suit his own conditions.

Mr. Taylor evidently wanted some more theoretical explanations. There is ample opportunity for those so inclined to make theoretical speculations. I have been unable to formulate a satisfactory explanation and that is why none is offered in the paper. Mr. Peek seems to think the matter very simple, but I do not think so. I do not see how the theory which he advances with respect to cylindrical and spherical electrodes can be applied to flat disks, where the distribution of the flux is very different.

Mr. Taylor apparently has concluded that the potential was measured to five volts and very properly questions such refinement. These figures in the paper are not single measurements, however, but in each case the average of 10 measurements rounded off to the nearest five.

Mr. Taylor asks if punctures appeared near the edges of the electrodes more frequently than elsewhere. The punctures were pretty fairly distributed over the entire surface, which I think is accounted for by the rounded corners.

**J. W. Milnor** (communicated after adjournment):· There has been considerable speculation concerning the causes of the phenomena observed by Mr. Farmer, and in view of this an analysis based on the theory of probability should be of interest.

Let it at first be assumed that the electric field between the electrodes is uniform, the increased flux density near the edges being ignored. The total area of the insulating material under test may be considered to be made up of a large number of elemental areas $dA$ having an average dielectric strength $E_a$, this value being very high. Their dielectric strength should vary according to the well-known law of error. That is, the probability curve of dielectric strength of an element of area is

$$P = \frac{h}{\sqrt{\pi}} \epsilon^{-h^2(E_a - E)^2} \qquad (1)$$

in which $h$ is a constant. If the area of one of the testing electrodes is $A$, we have $\frac{A}{dA}$ elements of area included between the electrodes, and the whole dielectric will fail at the weakest element of area. To estimate this dielectric will fail at the weakest element of area. To estimate this dielectric strength, let

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the area under the curve given by equation (1) be divided into $\frac{A}{dA}$ equal parts. Then the dielectric will most probably fail at the voltage represented by the center of the lowest section. This is near the boundary of the lowest section if the area is divided into $\frac{2A}{dA}$ equal parts.

The area under the probability curve included between the ordinate $(E_a - E)$ and the ordinate at negative infinity is given by the series

$$\text{area} = \frac{\epsilon^{-h^2 (E_a - E)^2}}{2\sqrt{\pi}\, h\,(E_a - E)}\left[1 - \frac{1}{2\,h^2\,(E_a - E)^2} + \frac{1.3}{4\,h^4\,(E_a - E)^4} - \ldots\right], \quad (2)$$

and since the total area under the curve is unity, each member of equation (2) is equal to $\frac{dA}{2A}$. Therefore

$$A = \frac{\sqrt{\pi}\, h\,(E_a - E)\cdot dA \cdot \epsilon^{h^2 E_a^2}\, \epsilon^{-2 h^2 E_a E}\, \epsilon^{h^2 E^2}}{1 - \frac{1}{2\,h^2\,(E_a - E)^2} + \frac{3}{4\,h^4\,(E_a - E)^2} - \ldots}, \quad (3)$$

Now if $dA$ is decreased indefinitely, $E_a$ becomes very large, so that $E$ is small in comparison, and $h$ becomes very small. In the limiting case, with $dA$ infinitely small, equation (3) becomes much simplified, and the result is of the form

$$A = C_3\, \epsilon^{-C_4 E} \quad (4)$$

Solving for $E$,

$$E = \frac{1}{C_4}\log_\epsilon C_3 - \frac{1}{C_4}\log_\epsilon A = C_1 - C_2 \log_{10} A, \quad (5)$$

in which $C_1$, $C_2$, $C_3$, and $C_4$ are constants.

Equation (5) shows that the dielectric strength of thin insulating material should vary as a simple logarithmic function of the area of the testing electrodes when conditions are such that the effects of the edges of the electrodes are small. It is evident from equation (5) that if $n$ separate tests of a given dielectric are made, using the same set of electrodes the difference between the average result and minimum result of the $n$ tests

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is most probably equal to $C_2 \log_{10} n$, this value being independent of the area of the electrode. It may also be shown that when $n$ is large the average deviation of the individual results from their mean is approximately $0.43\ C_2$, no matter what the area of the testing electrodes.

The increased electric flux density which occurs near the edges of the electrodes causes the observed dielectric strength to be generally less than called for by equation (**5**), and this discrepancy is larger, the smaller the area of the electrodes, or the greater the thickness of the material under test. This is evident when it is considered that either decreasing the area of the electrodes or increasing the thickness of the dielectric increases the

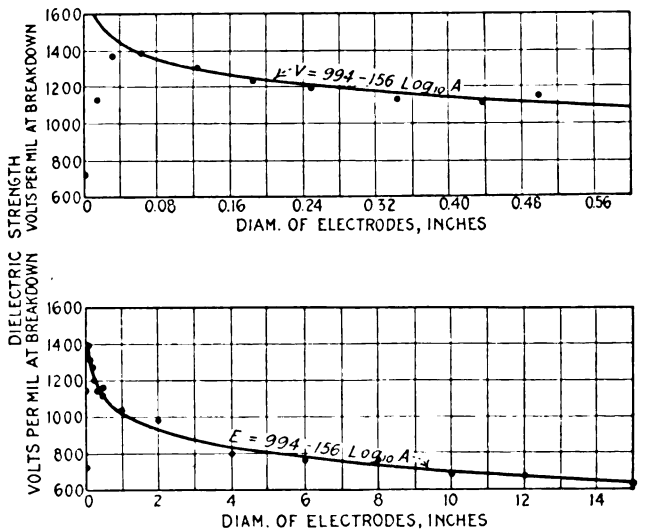


FIG. 4—EFFECT OF ELECTRODE AREA ON APPARENT DIELECTRIC STRENGTH OF VARNISHED CAMBRIC WHEN TESTED IN AIR, SHOWING AGREEMENT WITH THEORETICAL CURVE.

ratio of the maximum stress to the average stress, and also increases the proportion of the total area that is subjected to this maximum stress. When testing a single thickness of varnished cambric, relatively few of the failures occur near the edges of the electrodes; but when testing five or ten layers simultaneously, it will usually be found that a large proportion of the failures occur near the edges.

In order to illustrate the application of equation (**5**), the data given by Mr. Farmer for the dielectric strength of varnished cambric have been replotted (Fig. 4 herewith), and in the same figure has been drawn the curve

$$E = 994 - 156 \log_{10} A, \qquad (6)$$

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the area being in square inches. The constants of this equation were determined by trial. The curve agrees very closely with the observed data when the diameter of the electrodes is 1/16 in. (1.588 mm.), or greater. When the diameter is less than 1/16 in. the effect of the edges predominates. The difference between the average and the minimum results of the tests with a given electrode should be 156 $\log_{10} n$, being the number of tests. When $n$ is 10 this difference is 156 volts per mil at puncture; if $n$ is 15 the difference is 183; if $n$ is 21 the difference should be 206, etc. It will be observed that these differences as obtained from Table I of Mr. Farmer's paper are not greatly unlike the values given above.

The foregoing discussion indicates that the peculiar variation of the dielectric strength with the area of the testing electrodes is due mainly to irregularities of the material under test when the area of the electrodes is large, and to increased maximum flux density when the area is small. In deciding upon a size of electrodes to be adopted as standard, the area should be large if the aim of the tests is to determine the most representative value of the dielectric strength with the fewest number of tests. If, however, the most reliable result is desired while a minimum quantity of the material is used, a set of electrodes of small diameter should be chosen.

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DISCUSSION ON "TRUNK LINE ELECTRIFICATION" (KAHLER) AND "2400-VOLT RAILWAY ELECTRIFICATION" (HOBART), NEW YORK, MAY 20, 1913. (CONTINUED FROM P. 2147, PROCEEDINGS FOR NOVEMBER 1913).

*(Subject to final revision for the Transactions.)*

**Roger T. Smith** (by letter): Mr. Kahler's paper is interesting to English electrical engineers from the complete method of analysis adopted. The examples taken do not, however, invite criticism either of the constants or of the results since they are not comparable with anything in the way of steam or electric traction that we have or are likely to have in England.

Mr. Hobart's paper, while of course taking its examples from American practise, deals largely with certain fundamental constants for both steam and electric traction common to all railways. The method of analysis used and its lucid presentation conceal the great amount of work which must have been done in the preparation of the paper, nevertheless certain of the constants used in the calculation can only be considered as a first approximation. It may be useful to compare some of them with similar figures taken from English experience, and through the kindness of Mr. G. J. Churchward, locomotive, carriage and wagon superintendent of the Great Western Railway, England, I am enabled to consider several of the constants used by Mr. Hobart in the light of English experience on the longest English railway. While confirming or criticising Mr. Hobart's constants, it is to be remembered that the English figures put forward are for conditions for the most part very different from those in America. Without Mr. Churchward's help no steam figures could have been given, but even these figures are also only to be looked upon as approximations and Mr. Churchward must not in any way be held responsible for the manner in which the figures are presented.

| Page. | Line. | Constant or Assumption. | Deduction affected by assumption. |
|---|---|---|---|
| A. | B. | C. | D. |
| 1019. | 30. | Co-efficient of adhesion, 0.20. | Maximum available tractive effort. |
| 1020. | 6. | Average tractive effort over 100 miles for both loco. and load 9 lb. (10) per ton at average speed 50 mi. per hr. | The whole subsequent investigation depends on this figure. |

Mr. Hobart deals first with steam and electric constants for a fast passenger service covering 100 miles in two hours. Steam figures are given for a Pacific 4-6-2 type locomotive. The difference between the American ton and English ton may easily result in considerable confusion in comparing constants used in the two countries, and while my figures are all given in American tons of 2000 lb., the equivalent in English tons of 2240 lb. will be given enclosed in brackets. The author's engine weighs 115 tons (103) with 85 tons (76) adhesive weight,

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hauling a train of 750 tons (670). The comparative figures will for the most part represent results obtained with 4-6-0 type engines having a weight of 85 tons (76) with 62 tons (55½) adhesive weight, hauling passenger trains rarely exceeding half the weight of the American train.

The value of the coefficient of adhesion should not be taken as higher than 0.20. Experience with trains of about half the weight of the author's train gives 9 lb. train resistance per American ton (10 lb.) as a good average figure. Sufficient data is not available to determine whether the tractive effort is the same for the locomotive as for the coaches but it is to be remembered that this confirmation of the author's figures applies only to the coaches. There is reason to believe that train resistance is greater for the locomotive, and there is considerable advantage in dealing only with drawbar forces, such as can be measured on a dynamometer car, rather than with forces in the cylinder, the measurement of which by means of the indicator is extraordinarily difficult and liable to many errors.

| A. | B. | C. | D. |
|---|---|---|---|
| 1020. | 9. | Efficiency from cylinder to crank pin, 85 per cent. | The average i.h.p. required throughout the journey, the coal burnt and the journey efficiency. |

This efficiency would be more satisfactory if stated as between cylinders and rims of driving wheels. While curves of drawbar h.p. plotted with speed under specific conditions can be readily drawn to connect many points determined experimentally, the corresponding i.h.p. values are very hard to connect by a smooth curve. An average value of ratio $\frac{\text{drawbar h.p.}}{\text{i.h.p.}}$ may be taken to be 70 per cent and the indicated h.p. under the author's conditions would on this assumption be 1290 instead of 1320, thus checking the value of 85 per cent very closely.

| A. | B. | C. | D. |
|---|---|---|---|
| 1020. | 14. | Coal per i.h.p. = 3.5 lb. of calorific value of 14,000 B.t.u. per lb. | The coal burnt and the journey efficiencies from coal to cylinder and to wheel rims. |

On trials where the ratio $\frac{\text{d. b. h. p.}}{\text{i. h. p.}}$ was 0.70 the pounds of Welsh coal of a calorific value of 15,400 B.t.u. per i.h.p. were 2.75 which would probably correspond to 3 lb. per i.h.p. for the author's lower calorific value. Taking the actual figure of

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2.75 lb. for the better coal the journey efficiency from coal to drawbar is increased from 3.53 to 4.1 per cent.

| A. | B. | C. | D. |
|---|---|---|---|
| 1021. | 17. | Coal used for firing up and at end of journey 3000 lb. or 32½ per cent of coal used on 100 mile run. | Affects the reduction of journey efficiency from coal to drawbar. |

The figure 3000 lb. for the coal used for firing up and at end of journey would be considered very exceptional. About 800 lb. for firing up and 1100 lb. left in the firebox at the journey's end may be considered as representative figures for the largest English engines. This added to the coal used on the run would reduce the journey efficiency of coal to drawbar from 4.1 per cent to 3.2 per cent as compared with the author's figure of 2.85 per cent, the coal per drawbar h.p. amounting to 5.2 lb. instead of 6.86 lb.

For the electric locomotives if we accept the author's assumption that the resistance per ton of locomotive is the same as for the coaches, and the other carefully prepared and fair chain of efficiencies between the coal bunkers and the rims of the drivers given on pages 1022 and 1024, the final figure for this efficiency given by the author is 6½ per cent. With the steam figures already given for an English railway with locomotive coal of 15,400 B.t.u. or 6 h.p.hr. per lb., 57 per cent of the coal used by the steam locomotives would be required to haul the train electrically, as compared with the author's 47 per cent.

If steam locomotive working costs include coal, water, running wages and superintendence, lubricants, small stores, and locomotive repairs and renewals, the average cost of working a locomotive—that is, the total of these costs divided by the total number of locomotives in service—is about $5000 per annum.

Of these costs, coal and water account for about one third. It is suggested that these total costs, averaged over the whole stock, and then modified to suit each type of locomotive for which the average consumption of coal per mile is known would be the most useful figure for comparison between steam and electric locomotives. I regret not to be in a position to give this analysis for different types.

In comparing steam and electric locomotives for fast passenger service it must not be forgotten that, with increasing speed, the series motor falls off in output much more rapidly than the steam cylinder. The type of English steam locomotive most in favor for fast passenger service can give a measured (not calculated) drawbar h.p. of 1100 at 70 miles per hour. The Pacific type could of course give a greater h.p. Have any electric locomotives in America given a measured drawbar pull of 5900 lb. at 70 miles per hour?

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Agreeing with all that the author has said as to the purchase of electricity in preference to its generation by the railway, the British system of small municipal electric supplies in each town militates against the price of electricity offered by the large power companies falling to a sufficiently low figure except on the N. E. coast, where attractive prices are offered for traction. This has an important bearing in connection with the type of traffic dealt with in the second part of Mr. Hobart's paper under the head of "Mountain grade railways," where the hauling of heavy goods trains is considered firstly up 0.3 per cent grades and secondly up 1.5 per cent grades.

Here again our conditions are different. There are probably 700,000 privately owned traders' wagons in the United Kingdom for which the drawgear is, when new, tested to 56 tons (50). This permits of a maximum tractive effort of 13½ tons (12) and a maximum starting effort of 19 tons (17) and no locomotive giving more drawbar pull than this is required for general use. But apart from the loss of strength by wear, a considerable percentage of traders' wagons are much below this standard and in general make very heavy freight trains impossible. On some railways and in some classes of mineral traffic the company's own wagons are solely used and in such cases drawgear can be suited to heavier trains, but there is no difficulty in building, within the British load gage, steam locomotives (such for instance as those of the 2-8-0 Consolidation tank type with 70 tons (62½ tons adhesive weight) capable of pulling the heaviest trains containing traders' wagons which from the strength of their drawgear it is safe to marshall. In this country therefore, save in some special cases, the advantage of hauling heavier goods trains than can be hauled by a steam locomotive does not exist. In spite of this, the electric hauling of heavy goods trains in hilly districts is, after suburban passenger traffic, the most promising field for electric traction in this country on account of increase in possible speed.

Turning to the author's constants, and remembering the British drawgear limitation in the possible maximum weight of goods trains in general.

| A. | B. | C. | D. |
|---|---|---|---|
| 1031. | 19. | Total resistance of trailing load at 14 mi. per hr. = 4 lb. (4.5) per ton of loaded train, and 8 lb. (9) per ton of empty train, both at 14 mi. per hr. | The drawbar h.p. and all subsequent results. |

Different load conditions between the two countries make comparisons difficult. For a 560-ton (500) train the resistance per American ton was 6 lb. (6.7) and for the empties weighing 215 tons (190) the resistance per American ton was 15.1 lb. (15.9), but the speed was 20 miles per hour instead of 14 miles.

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The value 560 tons, approaches the possible British limit of train weight with a ruling gradient of 1 per cent.

| A. | B. | C. | D. |
|---|---|---|---|
| 1032. | 17. | Starting adhesion from 25 per cent to 30 per cent. | The maximum starting effort of locomotive. |

The adhesion at starting with the 2-8-0 type of goods engine is 0.32.

No useful comparison can be made with English conditions of the various constants leading to the efficiency for mountain grade locomotives between the coal and the drawbar. The amount of 30 per cent added for the coal used when the locomotive is standing can, however, be confirmed.

It is not possible to give a figure comparable with the author's figure for locomotive repairs. It is presumed that the figure of 10 cents per mile per 100 tons is an average figure and that for the Mallett locomotive under consideration it would be more.

Only one other figure used in the author's interesting comparisons between steam and electric locomotives on mountain grades can be given from experience this side, and that is with reference to the 16,000 traffic miles per annum of the Mallett locomotive. On a Welsh section including a ruling gradient for 2 miles of 2.0 per cent the average annual mileage of the 2-8-0 type of locomotive is 15,000.

It is a misfortune that the type of goods service in hilly districts for which electric traction is most suited in England is conducted under such very different conditions from those obtaining in America that a comparison with the author's figures is only possible in one or two instances. Such comparisons as have been made point to the close agreement of the author's constants with those obtained from one English railway.

**H. M. Hobart** (by letter): The more valuable portions of the discussions of the papers by Mr. Kahler and myself consisted in written contributions containing a large amount of quantitative data which required detailed analysis in order to disclose its significance. Indeed the significance of the contributions of Messrs. Babcock, Hall and Welsh have only become clearly apparent after studying them in conjunction with Mr. Babcock's paper entitled "Mountain Railway Electrification" which was published in the PROCEEDINGS for September 1913. In this paper Mr. Babcock considers a mountain railway which in many respects is practically identical with the case which I worked out in my paper, and it is only recently that I have been able to study all this material. This study has satisfied me that Mr. Babcock may be in error in extending his unfavorable conclusion as regards electrification of mountain railways to cases where the conditions are less favorable with respect to

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low cost of fuel, than in the exceptional case which he has considered. Mr. Babcock has based his steam locomotive costs on the use of oil purchased at about one cent per gallon or 42 cents per barrel. Oil fuel at such a price is equivalent to lignite (of a calorific value of 11,000 B.t.u. per pound) at a price of $1.60 per ton. For my example of a 96-mile mountain-grade railway I assumed a price of $2.40 per ton. This price is the lowest which could be considered representative. I devoted a page of my paper to pointing out and emphasizing the fact that with decreasing price of fuel the case for electrification rapidly became less favorable. The substitution of $1.60 per ton for fuel in place of my figure of $2.40 per ton would have greatly decreased the margin in favor of electrification.

It will be agreed that the price of about one cent per gallon (42 cents per barrel) for oil fuel is local in its application. At a price of 2 cents per gallon (84 cents per barrel) the item of $241,000 for locomotive fuel in Mr. Babcock's paper becomes $482,000 and increases his "Steam" total of $687,000 to $928,000. Furthermore, Mr. Babcock gives items for first cost of (I) Substations and (II) Contact System and Bonding, of $1,610,000 and $1,100,000 respectively, or a total of (I) and (II) amounting to $2,710,000. The output of the substations amounts to only some 47 million kw-hr. per annum. For a load of the character handled on his railway the substation outlay could certainly be reduced to much less than half of his figure. Without going at length into this matter, (which appears to be the chief point of difference between our estimates), I should unhesitatingly reduce Mr. Babcock's $2,710,000 by $800,000. Bond interest at $4\frac{1}{2}$ per cent comes to

$$0.045 \times 800{,}000 = \$36{,}000.$$

and when subtracted from the "Electric" total of $451,000, leaves ..... $415,000.

We now have

| | |
|---|---|
| Steam | $928,000 |
| Electric | 415,000 |
| Difference | $513,000 |

from which the cost of the electricity is to be defrayed. 55 million kw-hr. delivered annually to the substations at a price of 0.65 cents per kw-hr. amounts to an annual charge of $358,000, leaving a balance of $155,000 to cover taxes and depreciation. The net investment is

$$\$3{,}828{,}000 - \$800{,}000 = \$3{,}028{,}000$$

of which amount our $155,000 is 5.1 per cent.

This is a conservatively prepared statement and is interesting in disclosing (1) the effect of the fuel cost on the result and (2) the influence of the substation arrangements.

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I cannot agree with Mr. Babcock's optimistic estimates of the efficiency in his electric alternative and in a close analysis corrections ought to be introduced in this respect which would render the results a little less favorable to electrification. On the other hand I have taken no account of the decreased outlay for substation labor and supplies which would ensue from halving the number of substations and eliminating the feature of starting up the machinery just prior to the approach of each train.

If my results indicate the general order of magnitude of the investment and operating costs, it would appear that the increased capacity consequent upon the electrification of such a mountain grade railway should be amply attractive to justify serious consideration of electrification on the part of the executives of such roads.

Mr. Roger Smith's contribution contains data of very great value. Engineers will appreciate having available the precise figures which Mr. Smith, the chief electrical engineer, and Mr. G. J. Churchward, locomotive superintendent of the Great Western Railway of England have here presented. The Great Western data closely confirm my assumptions and in so far as they deviate therefrom will be of valuable guidance in arriving at more appropriate assumptions in investigations of this sort.

I accept Mr. F. W. Carter's suggestions as very much to the point. Mr. F. C. Merriell alludes to the important superiority of electrical operation as regards immunity from the difficulties attending steam-locomotive traction in extreme cold weather. The point is one of much importance.

With reference to the discussion of steel rectifiers by Messrs. Armstrong and Murray, I should like to refer to pages 136 and 137 of a paper entitled *The Relative Costs and Operating Efficiencies of Polyphase and Single-Phase Generating and Transmitting Systems*,* in which I called attention to the useful and useless lines on which such apparatus may be developed. If Mr. Murray will refer to that paper and to his own experiences he will see that there is need for a revision of his statement that "the power house of the single-phase and continuous-current systems are about a stand-off." Mr. Parshall expresses the opinion that the paper credits the steam locomotive with a better performance than is representative. The criticisms of Messrs. Murray and Wynne, on the contrary, appear to be to the general effect that I have underestimated the performance of the steam locomotive.

It is interesting to contrast the conclusions of Mr. George Hill with those of Mr. Babcock. The former states that his firm has satisfied itself in the course of its investigations that electrification will make a very satisfactory showing for many cases of heavy mountain grades: the latter has reported on

*TRANS. A. I. E. E., Vol. XXXI (1912).

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"every mountain railway exit from the Central California valleys, and on other mountain districts in other parts of the West Coast country" and the conclusions have invariably been adverse to electrification.

Mr. Wynne criticises my 78 per cent annual substation efficiency for the mountain-grade service as being too high, and recommends that it be decreased by from 7 to 10 per cent. In Mr. Babcock's paper the annual substation efficiency is taken as 90 per cent. In my opinion this is 10 per cent higher than he could obtain by any practical means for the service he describes. In Mr. Wynne's opinion Mr. Babcock's figure is 20 per cent too high.

I am especially glad to have the data which Messrs. Hall and Welsh give relating to the cost of Mallett locomotives. Although the figures which I obtained for the cost of Malletts were from very reliable sources, nevertheless, I should have employed somewhat lower prices had these further data been known to me. The comparative result would, however, not be much affected, if at the same time, I had taken the electric freight locomotives at $350 per ton, the figure employed by Mr. Babcock in his paper, in place of the figure of $450 per ton which I employed for the electric locomotives in my estimates.

**A. B. Babcock** (by letter): Mr. Hobart is satisfied "that Mr. Babcock may be in error in extending his unfavorable conclusions as regards electrification of mountain railways to cases where the conditions are less favorable with respect to the low cost of fuel than in the exceptional case which he has considered." It seems impossible for me to make plain enough to be understood that my conclusions are not unfavorable to electrification of any railways, mountain or plain, except those that I have investigated personally and reported on adversely. While these concern the exits from the Central California Valleys, and some other mountain districts on the West Coast, there are many other districts in which electrification may be extremely profitable. I am not aware that I have ever made a statement favorable or unfavorable to electrification in general.

Mr. Hobart, if I understand his argument, goes on to assume a hypothetical value of fuel and from that argues himself into a position contrary to that resulting from my analysis of the Tehachapi figures. With reference to this, permit me to call his attention to my discussion of his paper as published in the PROCEEDINGS. "While in the hypothetical case, from a given set of assumptions one may argue himself into almost any desired position, in practise the hard and unyielding physical facts are met." He also states, "For a load of the character handled on his railway the substation outlay could certainly be reduced to much less than half his figure." Again permit me to call his attention to the fact that actualities are considered in my Tehachapi paper and to refer him to the paragraph wherein I said, "This traffic must be handled as circumstances require.

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It cannot be spaced conveniently for power demands as many engineers and power men have suggested, but the terminal yards must be cleared as the cars accumulate."

Mr. Hobart contrasts the conclusions of Mr. George Hill with mine. Mr. Hill's viewpoint and mine are different. Again I will refer him to my Tehachapi paper, first and third paragraphs thereof.

From the foregoing quotations it would appear to me that Mr. Hobart has not read the Tehachapi paper with the care that would justify his positive statements with reference to my attitude. For his information I will state that the said Tehachapi paper was written in the hope that it would draw out a discussion wherein, if my office has been in error for the last ten years with respect to such problems, these errors would now be pointed out by those who are competent to have opinions on this subject. So far only Mr. Hobart has offered a criticism. He appears to have read it without discovering that it deals with facts,—with things as they are, not with things as both he and I might wish to have them. Only a few weeks ago I stated to a representative of a prominent engineering firm that I would be very glad to be shown that my conclusions are erroneous, if such is the fact, and I made the offer at that time, which offer still stands open, that although I had stated in the Tehachapi paper the absolute operating facts as taken from the company's records, I am ready at any time to turn over to competent members of any of the large electrical manufacturing companies, all of the operating data that can possibly cast light on these problems, to give them access to all of the facts in connection with the property, and if they can convince our operating officials that there is a profit in the electrification of any one of the mountain outlets from Central California, as operated by this company, or as can be reasonably operated by this company, I stand ready to confess my error as publicly as I have stated my conclusions; but I will neither take part in general discussions that lead nowhere, nor will I pick up straw men after they have been knocked down.

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*(Subject to final revision for the Transactions.)*

# INHERENT VOLTAGE RELATIONS IN Y AND DELTA CONNECTIONS

BY ROYAL W. SORENSEN AND WALTER L. NEWTON

ABSTRACT OF PAPER

The paper gives the results of experiments made with a miniature simple transmission system to demonstrate the inherent voltage relations with different combinations of Y and delta connections.

The experimental system consisted of a 7.5-kv-a. revolving field generator, with coil terminals which could be connected either Y or delta, and two banks of transformers each composed of three shell-type 3-kv-a. units. All inductive and capacity effects in the transmission line were eliminated. The tests were made under constant conditions, with non-inductive load.

The authors give the results of four groups of tests, on four different systems of connections, pointing out the advantages and disadvantages of the several systems. In each case tests were made without load, with balanced load, and with load on one phase only, for various conditions of grounding. Typical voltage diagrams are given, to show what happens under various conditions of load.

The authors discuss certain cases where the use of auto-transformers is advantageous, and the effects of different ways of connecting them.

THE HIGH survival value which the subject of Y and delta systems has as a matter of discussion almost warrants the assumption that inherently neither system can be said to be generally inferior to the other for the transmission and distribution of electric energy. On the other hand, if there is to be any choice of either system even for special work such as long-distance transmission at high voltage, it would seem as though the choice must be based upon certain features inherent in the method of connections even though these features may not in themselves be bad, but rather become conducive to trouble only when combined with other features incident to that particular condition.

It is the purpose of this paper, therefore, merely to bring to the attention of those interested, experiments made with simple Y-connected and delta-connected systems and to show, if possible, wherein the advantages of one with respect to the other may lie.

The simplest system which could be constructed would be



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that of a single three-phase line supplied at one end through step-up transformers by the generator and at the other end giving out its energy to the connected load through a bank of step-down transformers.

As there can be made with each three-phase bank of transformers four combinations of connections, and as the generator and the receiving motor may be connected either Y or delta, it is readily evident that even in a very simple system there may be made a large number of combinations.

The generators as a rule are connected Y because of the better wave form obtained, as seen in Figs. 1 and 2, and because of the convenient ground point which is then provided. Experience has practically made standard the delta connection for the low-tension windings of both the step-up and step-down transformers, thus leaving for consideration only the arrangements of the high-tension windings of step-up or step-down transformer banks. These may both be connected Y, as has been very generally done, and the neutral points may be grounded or not grounded, the grounded condition being, however, the one in general use. They may both be connected delta or one may be connected delta and the other connected Y, a condition not usual, but one which in some cases has been thought desirable.

Having made a selection as to the arrangement to be adopted in any particular system, it is of course obvious that this system must be carried throughout for any points of multiple connection of transformer banks or transmission lines, because of the impossibility of delta-Y banks being run in parallel with delta-delta banks.

## Description of Tests

To determine the inherent relations, a miniature system consisting of a 7.5-kv-a., revolving field generator, with coil terminals brought out so that it could be readily connected Y or delta, and two banks of transformers each consisting of three shell-type 3-kv-a. units, was constructed. All inductive and capacity effects in the transmission line, which was in this case only the necessary leads for connecting together the high-tension windings of the step-up and step-down transformer banks, were entirely eliminated. This must be kept in mind when considering the conclusions drawn from the tests.

All tests were made for constant conditions and the load used was non-inductive. Potentials were measured with a multicellular electrostatic voltmeter, which on closed circuits

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was carefully checked with a standard portable dynamometer instrument.

All connections were carefully insulated from each other and from ground, as was also the frame of the generator, except

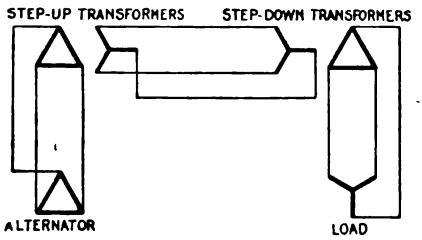


FIG. 3

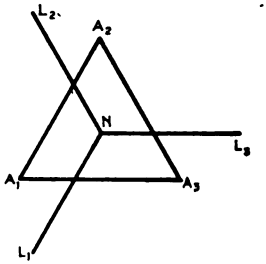


FIG. 4

in such cases as it was well grounded with a copper ground. In all tests the transformer cores and cases were well grounded.

The first group of tests was made on the system connected as in Fig. 3, without load, with balanced load, and with load

TABLE I*

| Load | Gr'd point. | Open point. | Maximum per cent volts. | | | | |
|---|---|---|---|---|---|---|---|
| | | | H. T. to Gr'd. % H. T. | L. T. to Gr'd. %L. T. | H. T. to L. T. % H. T. | H. T. to L. T. % L. T. | N. to Gr'd % H. T. |
| 0 | None | None | 57.7 | 57.7 | 82.0 | 163.0 | 0 |
| 0 | Neutral | " | " | " | " | " | " |
| Balanced | None | " | " | " | " | " | " |
| " | Neutral | " | " | " | " | " | " |
| 1 phase | None | One H.T. line | 51.0 | 69.5 | 90.0 | 180.0 | 18.2 |
| " | Neutral | " | 73.0 | 167.0 | 138.0 | 276.0 | 0 |
| " | None | One load lead | 74.5 | 70.0 | 100.0 | 200.0 | 4 |
| " | Neutral | " | 62.4 | 71.5 | 104.0 | 209.0 | 0 |
| Balanced | One H.T. line | None | 100.0 | 65.0 | — | — | — |
| | N & 1 " " | " | 91.2 | 57.7 | — | — | 0 |

*In these tables readings with ungrounded generator frame are omitted (exceptions noted in Tables II and IV), as this condition so rarely exists in practise.

on one phase only, for various conditions of grounding. Some typical results of these tests are shown in Table I. When one phase only is loaded such condition is obtained in one of two ways: by opening a high-tension line, or by opening a low-tension line on the load end.

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Fig. 4 shows the no-load voltage diagrams of high- and low-tension lines superimposed upon one another. The step-up and step-down transformers being identical, the delta represents voltages of generator, primaries of step-up transformers and secondaries of step-down transformers. Line voltages, secondaries of the step-up, and primaries of the step-down transformers are shown by the Y. If, as was assumed, the diagram is drawn to scale, it would be supposed that a measurement from any point on the delta to any other point on the Y would give the voltage between corresponding points on primary and secondary of transformers. This, however, was found not to be true in many instances. With no ground point on the system except the transformer cases, the electrostatic strains would be anywhere from 50 to 100 per cent greater than the values obtained by measurements from the diagram. The neutral point of the Y, which should normally be at ground potential, was found to be at some distance above. It was in fact found

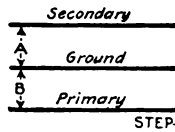
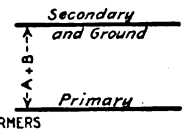



FIG. 5




STEP-UP TRANSFORMERS

FIG. 6

that no point on the entire system was exactly at ground potential, except of course the transformer cases, and even the frame of the alternator was found to be at a potential above ground greater than normal line voltage. These facts can lead to but one conclusion, namely, that the conditions on all systems cannot be truly represented on one plane.

On this assumption, a great number of readings were taken and it was found that each section of the system might lie in a totally different plane, but that these planes are always approximately parallel.

An end view, then, of Fig. 4 would appear as in Fig. 5, in which each line represents the plane on which the respective diagrams would have to be drawn to represent correctly the readings obtained. No definite law seems to govern the relative position of these planes. On one day the distance between them may be twice that obtained on another. However, the primary and secondary planes are always on opposite sides of ground, as shown.

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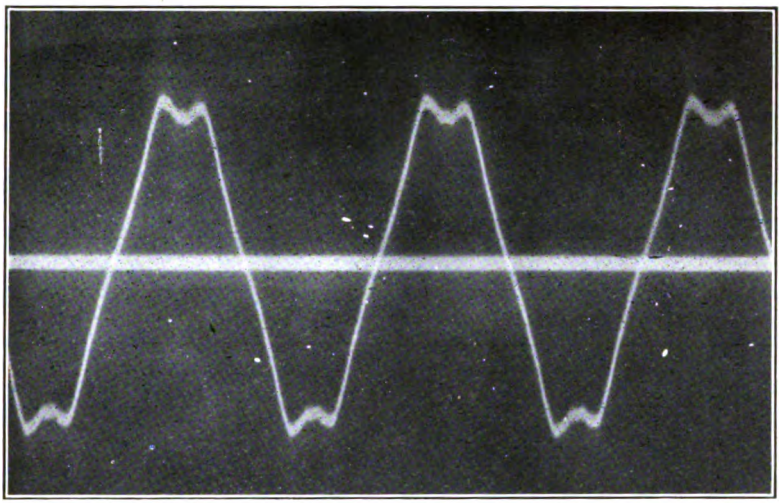
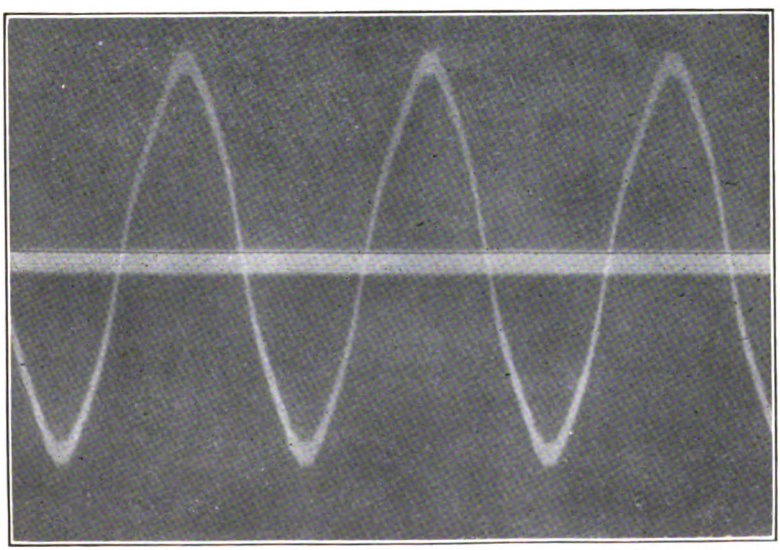


[SORENSEN AND NEWTON]

FIG. 1—VOLTAGE CURVE, CENTRAL LABORATORY ALTERNATOR. 110 VOLTS, 50 CYCLES. DELTA-CONNECTED.



[SORENSEN AND NEWTON]

FIG. 2—VOLTAGE CURVE, CENTRAL LABORATORY ALTERNATOR. 110 VOLTS, 50 CYCLES. Y-CONNECTED.

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The grounding of the Y neutral brings the transmission line plane to ground potential, but maintains a nearly constant potential between this plane and the generator plane, so that the potential between generator plane and ground is doubled, as in Fig. 6. When the generator frame, which heretofore had been well insulated, was thoroughly grounded, all potentials were brought to the same plane and the voltages read corresponded to those measured from the diagram, in Fig. 4.

As load is added to the ungrounded system, the distance between the respective planes decreases, and appears to be some function of the load. When loaded, the difference between them is inappreciable. This is true of unbalanced as well as balanced loads. Conditions, then, are better at load than at no load, or very light load. (See Table I.)

The second group of tests was made with the same trans-

TABLE II

| Load | Gr'd point. | Open point. | Maximum per cent volts. | | | | |
|---|---|---|---|---|---|---|---|
| | | | H. T. to Gr'd. % H. T. | L. T. to Gr'd. %L. T. | H. T. to L. T. % H. T. | H. T. to L. T. % L. T. | N. to Gr'd % H. T. |
| † 0 Balanced | None " | None " | 57.7 " | 61.0 " | 85 " | 167.0 " | 0 " |

†Generator frame not grounded.

former arrangement but with the generator connected Y. The tests made under these conditions gave results as in Table II, which are very similar to those of the first group, in that there still remains the tendency for the voltage planes to separate on the ungrounded system, at light load. This condition is probably better, however, than the first, due to the better wave shape obtained with the generator in Y, as can be seen by a comparison of Figs. 1 and 2.

From these data the following conclusions for a Y-connected transmission line may be drawn: The generator should be connected Y. The neutral point should be well grounded at both ends to relieve electrostatic strains. There is, of course, the objection to a grounded neutral, that if a line becomes grounded also, one phase is short-circuited. The second point, which fortunately does not often arise in practise, is that all alternator frames, motor frames, and transformer cases should

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be thoroughly grounded, not only for the foregoing considerations, but also to protect the lives of operators and linemen.

The disadvantages of Y-connected transmission lines may be summed up: Difficulty of obtaining a satisfactory ground on the neutral and overload or short circuit of one phase by partial or complete grounding of a line.

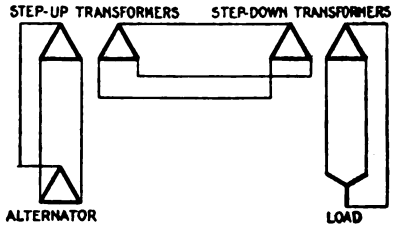


FIG. 7

The third group of tests was made with the system connected as in Fig. 7, with the same load conditions as in the previous set of tests. With this arrangement the normal stresses are about the same as with the Y connections (see Table III), and the unbalancing of load causes no serious variation in voltage relations, but there remains the tendency for the circuits to

TABLE III

| Load | Gr'd point. | Open point. | Maximum per cent volts. | | | | |
|---|---|---|---|---|---|---|---|
| | | | H. T. to Gr'd. % H. T. | L. T. to Gr'd. %L. T. | H. T. to L. T. % H. T. | H. T. to L. T. % L. T. | N. to Gr'd % H. T. |
| .0 | None | None | 58.3 | 57.7 | 91.2 | 105.0 | — |
| Balanced | " | " | " | 59.0 | " | " | — |
| 1 Phase | " | OneH.T. line | 60.1 | 69.1 | 104.0 | 120.0 | — |
| " | " | One load lead | 65.0 | 67.2 | 109.0 | 126.0 | — |
| 0 | OneH.T. line | None | 100.0 | 64.5 | 135.0 | 156.0 | — |

lie in different planes, which separate decidedly with a removal of the ground connections to the generator frame. In this case, again, the bad wave form of the alternator connected delta is objectionable. On the whole this system is not to be recommended, as conditions seem to be particularly unstable, and there is no possibility of obtaining a ground point if occasion demands.

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The fourth group of tests was made with the same transformer connections as in group three, but with the generator connected Y, giving the better wave form. This is apparently the ideal condition, as with such an arrangement it is unnecessary to ground this neutral in order to relieve abnormal elec-

TABLE IV

| Load | Gr'd point. | Open point. | Maximum per cent volts. | | | | |
|---|---|---|---|---|---|---|---|
| | | | H. T. to Gr'd. % H. T. | L. T. to Gr'd. %L. T. | H. T. to L. T. % H. T. | H. T. to L. T. % L. T. | N. to Gr'd % H. T. |
| † 0 | Gen. N. (Ng) | None | 58.7 | 57.7 | 94.4 | 109.0 | 0 |
| " | None | " | 58.2 | " | " | " | 3 |
| Balanced | Gen. N. | " | 57.7 | 60.0 | " | " | 0 |
| 1 Phase | " | OneH.T. line | 71.7 | 90.0 | 167.0 | 192.0 | 4 |
| " | " | One load lead | 81.2 | 84.0 | 142.0 | 164.0 | " |
| 0 | 1 H. T. line & Ng | None | 100.0 | 58.0 | 145.0 | 167.0 | " |
| " | OneH.T. line | " | " | 63.7 | 148.0 | 168.0 | " |
| Balanced | 1 H. T. line & Ng | " | " | 58.0 | 145.0 | 167.0 | " |

†Generator frame not grounded.

trostatic strains between windings. (See Table IV.) All neutral points remain close to ground potential, even under unbalanced load. There being no grounded neutral on the system, the danger of a short-circuited phase by grounding is entirely obviated, unless two lines should become grounded simultaneously.

## Voltage Diagrams

A few voltage diagrams might help to make clear just what happens under various conditions of load. To avoid needless repetition of similar figures, diagrams of the results obtained in the fourth group of tests are taken as typical.

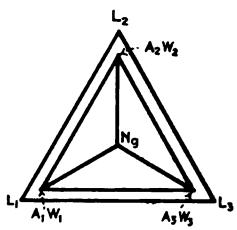


FIG. 8

Fig. 8 represents conditions under balanced load, in which the Y is the generator diagram, with the neutral at *Ng*. The delta $A_1$, $A_2$, $A_3$ represents the primaries of the step-up bank of transformers, and $L_1$, $L_2$, $L_3$ the secondaries of this bank and the primaries of the step-down transformers. The diagram of the secondaries of step-down

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transformers connected in Y, corresponds to $A_1$, $A_2$, $A_3$ and is indicated by $W_1$, $W_2$, $W_3$.

If, now, one line is opened between step-up and step-down transformers, conditions result as in Fig. 9, which is lettered to correspond with Fig. 8. The heretofore symmetrical figures become considerably distorted. $W_1$, $W_2$, $W_3$ becomes a straight

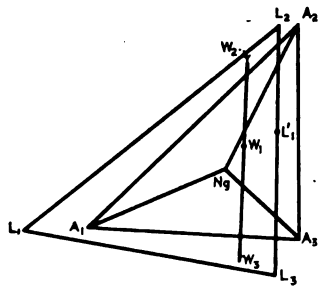


FIG. 9

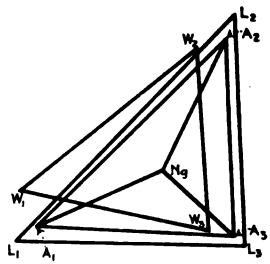


FIG. 10

line, and is therefore in series from $W_2$ to $W_3$. The diagrams of the secondaries of the step-up bank and of the primaries of the step-down bank of transformers are no longer coincident. The former is shown by the triangle $L_1$, $L_2$, $L_3$ and the latter by the straight line $L_2$, $L_1'$, $L_3$. The distance $L_1$-$L_1'$ represents the voltage across the open switch.

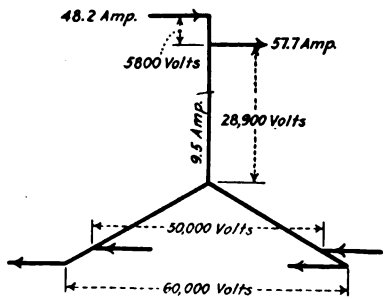


FIG. 11

An open line between step-down transformers and the load gives Fig. 10. The distortion is not so noticeable as in the previous case.

## AUTO-TRANSFORMERS

The economic advantage of using auto-transformers for changing from one phase to another and for making slight

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voltage changes when it has not been necessary to keep the two systems insulated from each other has caused them to be quite extensively used.

*Example*: A certain large power company had as one source of supply a plant which delivered power to the main distribution center, over a 125-mile (201-km.) line at a potential of 50,000 volts. In the new development 60,000 volts was selected

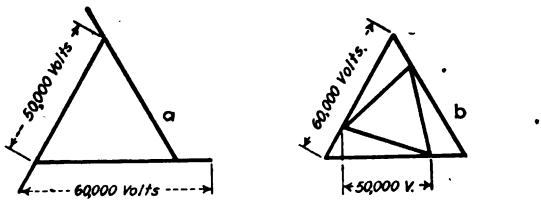


FIG. 12

as a standard for long distribution feeders, and as the line insulation would not permit the old system to be raised to this voltage, the two projects were tied together by means of three auto-transformers, which were Y-connected and would carry, on the 50,000-volt taps, 5000 kv-a. The connections and currents for this bank of auto-transformers are shown in Fig. 11.

This is the most common arrangement of auto-transformers because it is both convenient and economic, and the only one

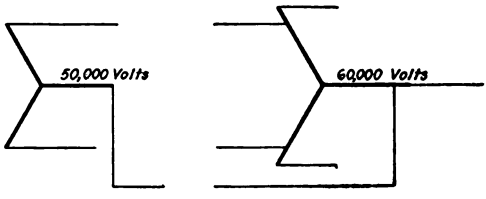


FIG. 13

which will be considered, although either the extended delta or the delta connection as shown in Fig. 12, *a* and *b*, might have been used to good advantage.

When such an auto-transformer is used, it is connected as in Fig. 13. For such an arrangement there may be two conditions; grounded neutral and ungrounded neutral. With grounded neutral the triple-frequency e.m.f. which exists from line to ground may become very dangerous, particularly if the line has

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considerable electrostatic capacity, as would be the case in the assumed problem, because of the intensifying effect of the third harmonic in the charging current. In some tests made, the maximum stress was found to approach three times normal potential for the neutral of the auto-transformer bank grounded.

With the neutral of the auto-transformer bank ungrounded, stresses running up to 50 per cent of line voltage may be measured from ground to neutral, which is of course not a serious matter, as the maximum stress will remain from line to ground and will not be changed from normal value.

Laboratory tests for this connection indicated that the maximum voltage strain from the lower potential lines to ground would be about half the sum of the high-voltage and the low-voltage, which in this case would be one-half of 60,000 volts plus 50,000 volts, or 55,000 volts.

## Transformer Design

When transformers were made in small sizes only, particularly if they were shell type, there was some advantage in having the windings connected Y for the high-tension side of the bank, as this allowed a smaller number of coils and less insulation, because the normal strain was 57.7 per cent of that of delta-connected transformers. The increase in size of units and the provision for maximum strain where one line becomes grounded have made these economic advantages obsolescent, except in some very special cases of small, high-voltage units. Hence, from the point of design and manufacture, there is no advantage for either Y or delta construction.

## Appendix

It may be of interest to consider an actual network diagram of the system of a large western power company, as shown in Fig. 14. The following nomenclature is used:

$A$, engine-driven alternator.
$TA$, turbine-driven alternator.
$T$, transformers.
$AT$, auto-transformers.

The numerals indicate the voltage at various points on the system. For simplicity, the location of switches has not been shown. Several small generating stations on the system are not shown.

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Power house No. 1 contains three (shown as one in diagram) engine-driven alternators delivering power at 15,000 volts directly to the busbars. The two turbo-generator sets generate at 9000 volts and step up to the busbar voltage through auto-transformers. In substation No. 1 this is stepped up through transformers to connect with a 50,000-volt line, and in substation No. 2 it connects with a 60,000-volt line through transformers.

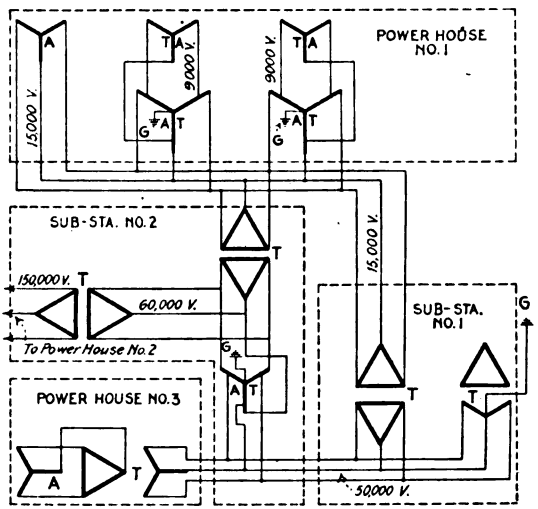


FIG. 14

Power house No. 2 (not shown) is a hydroelectric plant. The generator voltage is stepped up with delta-Y (grounded neutral) transformers to 150,000 volts, at which voltage it is delivered to substation No. 2, where it is transformed to 60,000 volts as shown. The 50,000-volt line from power house No. 3 is connected to the 60,000-volt line through auto-transformers. Substation No. 1 contains a bank of transformers connected Y-delta, with the neutral grounded and the secondary on open circuit.

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*(Subject to final revision for the Transactions.)*

# ELECTRIC HEATING AS APPLIED TO MARINE SERVICE

BY C. S. MC DOWELL AND D. M. MAHOOD

ABSTRACT OF PAPER

Electricity is being adopted to a great extent for space heating in marine work because of the simplicity and low cost of installation, saving in weight, freedom from leaks, noises and disagreeable odors as compared to steam heat, availability for heating of individual rooms, ability of placing heaters where most efficient, portability so that storerooms and other seldom-used spaces may be readily heated when desired, ease of regulation so that individual staterooms, etc., can be maintained at any desired temperature without affecting the whole system.

A comparison of convector and radiant heaters is given, the proper use of each type is shown, and the conclusion drawn that for space heating on shipboard with metal decks and bulkheads, the convector heater is most efficient.

Curves are given showing results obtained on tests to determine the best type of heater for shipboard and desirable features of heater are indicated.

With low cost of electricity on shipboard, electric heating compares favorably in cost of maintenance with steam heating. It interferes very little with the lighting load, thus increasing the load factor, and seldom requires extra generator capacity.

THE SUBJECT of this paper was selected because it presented a means of placing before the Institute the advantages of electric heating, which have become more prominent in marine than in land service; and because marine service has very thoroughly taken up this subject, with the result that many installations have been made. Electric heating, properly applied, fits itself well to the conditions of marine engineering, where the high quality of service and its many desirable advantages over balance what increased cost of electric power there may be.

Electric cooking, with its many advantages, included in which are the saving in time and food, improvement in quality of food, ease of installing and operation, safety and sanitation, are well known, and it seems unfortunate that the use of such appliances has been held back in this country as much as it has, and is not receiving the attention it has been getting abroad.

The gradual increase in the use of electrically heated industrial apparatus is going on, the safety, saving in time and improved



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quality of work creating a popular demand in many classes of apparatus.

Electric air heating of spaces, upon which we will go into detail in this paper, is now rapidly coming into popular demand, its advantages, properly applied, making it a worthy competitor to other methods of air heating in marine engineering. The increased cost of operation over steam heat, although high in proportionate percentage is not very great in actual dollars in view of the low cost of generation of electric power aboard ships, and is further balanced by the convenience of locating the heat source where most efficient use of it can be made, the simplicity and low first cost of installation, especially where the air space to be heated is far from the boiler or engine room, the possibility of reliable automatic control of temperature, the low cost of repairs with little attention required, and the improved quality of service with freedom from leaks, noises, disagreeable odors and the other inherent objections to steam heating systems.

In some cases in the past, electric air heating systems have been failures, but usually these have been traced down as resulting either because the apparatus installed was the wrong design or insufficient for the conditions, the conditions such that an electric air heating system should never have been selected, or the particular electric heating system installed did not suit the conditions existing. In some places a small two- or three-lamp radiant heater was installed to heat a comparatively large space, the small radiator being selected probably because of high cost of power or because of the desire for appearances rather than for performance. It should be carefully considered before electric heating is installed whether the advantages of this system will overbalance the reduced cost of operation with steam, as unsatisfactory results in some past installations have proved hard handicaps to overcome, and have prevented installations that would have been very creditable. Care should be taken in selecting the design of heater and most appropriate method of installation, rather than placing appearances first with a resultant sacrifice of results, which appears to have been the practise in some past installations. As with electric cooking and industrial apparatus, electric air heating can compete with other systems only because of its adaptability, and this must be considered and made use of or the system will be found unsuccessful.

Heat is dissipated as we know, by conduction, radiation and

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convection. In considering electricity for space heating on shipboard we encounter, as a rule, metal bulkheads and decks which are good conductors of heat and every effort should therefore be made to minimize conduction losses. The radiant and convector heaters, named from the manner in which the heat is furnished, have different conditions to meet.

The radiant heaters or electric radiators dissipate the heat principally by sending off radiant energy, raise the temperature of opaque bodies in its path, and as they respond instantly when turned on have been found adaptable where a small amount of immediate warmth and intermittent use is required, such as in rooms not in general use, and where it is not desired that the temperature of the entire room be increased. Its efficiency for space heating on shipboard depends upon the material of the bulkheads and decks. As these are as a rule metal, which is a very good conductor of heat, a large part of the radiant energy is converted into heat upon striking the bulkheads and decks, is carried by conduction through the skin of the ship to the water and lost, or carried through the bulkheads and decks to the surrounding compartments and lost so far as the individual compartments are concerned. A feature observed in the radiant heater worthy of mention is the feeling of satisfaction when sitting in front of it (absent in a convector), caused by the cheerful glow present and, as had been stated by some authorities, the additional possibility of a physiological effect caused by the radiation of the higher frequency rays of infra red such as is experienced in sun baths.

Convectors heating the air in contact with resistance units, start convection currents which increase and maintain the temperature of the whole room. In space heating, where the surrounding walls are of metal, it has been seen that radiant heaters are inefficient in heating the air, and for this same reason in convectors the radiation losses should be kept down to a minimum. As the radiation increases as a function of the temperature, the temperature of the element should be kept low. Also it is better to heat a large volume of air a few degrees than a small volume of air a proportionately greater number of degrees. The former instead of rising rapidly to the top of the room and there losing its heat through the metal deck above will spread out more and warm by convection the air of the whole room.

To indicate the division of forms of heat dissipated by the

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convector and radiant heaters the following was experimentally determined, using standard constructions:

| | Radiant heater | Convector heater |
|---|---|---|
| Convected heat.... | 40 per cent | 90 per cent |
| Radiated heat..... | 55 per cent | 5 per cent |
| Conducted heat.... | 5 per cent | 5 per cent |

The design of radiator appears to have settled on the glow-lamp type, although resistance wires operating at a red heat are coming into use. The location of the radiator is facing and within three or four feet from the person using it. In the standard designs of radiant heater, the glow lamp is the source of heat, and the

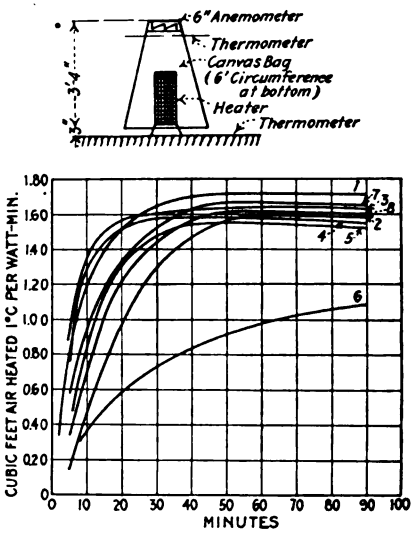


FIG. 1—AIR HEATED BY VERTICAL DRAFT.

commercial designs include two, three and four-lamp units, the lamps being either 250 or 500 watts each, as desired.

The design of convector heaters of the various manufacturers differs principally in the details of construction of the heating units. The formation of resistance units constructed of special resistance wire or ribbon, insulated and protected in various ways, and operating as close as practicable to a tempeature best suited for the supply of convected heat, mounted in a manner to permit of efficient circulation of air, protected by a strong guard which does not restrict circulation and provided with a properly shaped deflector to give distribution of air desired, makes up this form

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of heater. Practise has settled upon a long low heater as preferable, which design, aided by a properly shaped deflector, permits of sending the heated air out from the floor, where better mixture and uniformity of temperature is obtained without the danger of concentration of high heat at the ceiling with a greatly reduced temperature lower down. A case has been cited of poorly installed heaters where the upper berths of staterooms have been surrounded by air at such a high temperature to make it uncomfortable, whereas a glass of water placed on the floor has been close to the freezing point.

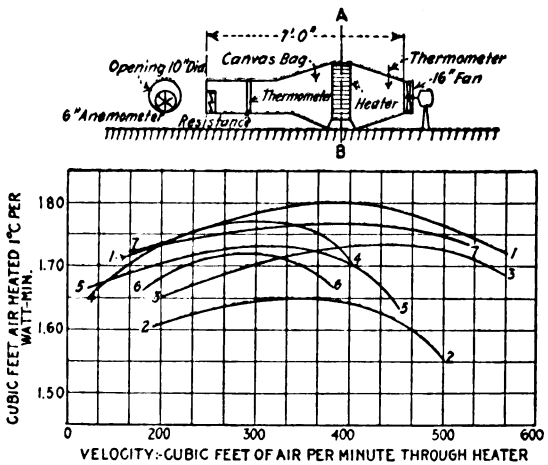


FIG. 2—AIR HEATED BY FORCED HORIZONTAL DRAFT.

| No. | Input. | Cross-section-A—B |
|---|---|---|
| 1 | 3300 watts | 169 sq. in. |
| 2 | 2340 " | 180 " " |
| 3 | 3000 " | 238 " " |
| 4 | 1760 " | 121 " " |
| 5 | 2240 " | 210 " " |
| 6 | 1220 " | 138 " " |
| 7 | 3250 " | 130 " " |

The design of the heating element is influenced greatly by the desired standard of safety to be upheld, and this has brought out designs where the vibration and jar of marine service cannot cause disarrangement and possible arcing. Insulation of the supporting feet to prevent conduction of heat to the steel deck and bulkheads is looked after during installation and need not be considered in the design of the heater. The essential requirements of convector heaters are long life, maximum heat by convection available in a comparatively short time, a construction conveniently installed, safety, good appearance, and a flexible

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design for different capacities desired in the various locations.

The operation of various designs of convector heaters is shown by the following curves obtained experimentally:

Fig. 1 shows the convected air by natural draft measured by anemometer and indicates the cubic feet of air heated one deg cent. per watt-minute. This figure also contains a sketch showing the manner in which the convected air was measured.

Fig. 2 shows the air heated by forced horizontal draft, indicating in cubic feet of air heated one deg. cent. per watt-minute, and shows the variation with velocity of the operation obtained,

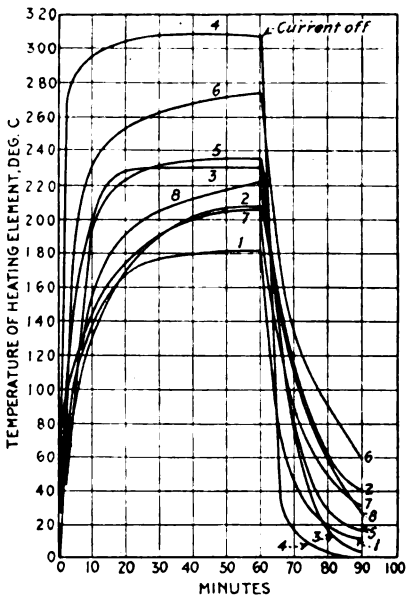


FIG. 3—CURRENT OFF AT END OF SIXTY MINUTES.

and is useful in considering such heaters for indirect heating, in which the heaters are placed in the ventilating ducts.

Fig. 3 shows the temperature rise of heating elements plotted against time for the respective heaters, and is useful in judging the performance of such heaters.

Fig. 4 shows the temperature distribution taken in a room 12 ft. by 21 ft. and 17 ft. high, with and without the use of deflectors of various shapes, and using one heater. Fig. 5 shows the temperature distribution in the same room as Fig. 4, only with the heater placed in the center of the room.

Fig. 6 shows the temperature distribution in a room 8 ft.

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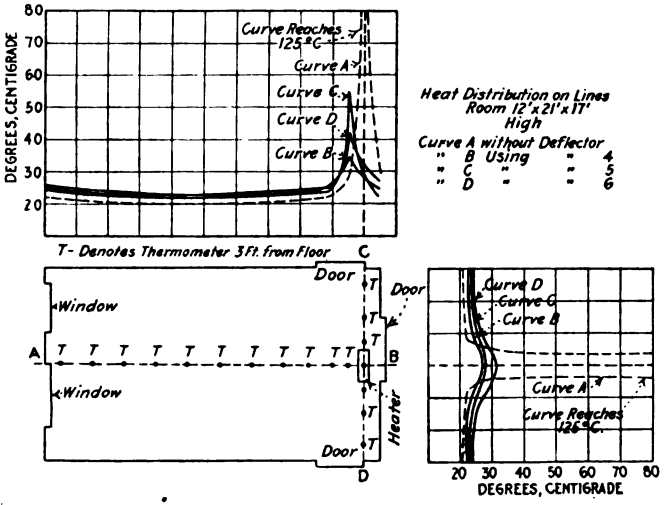


FIG 4

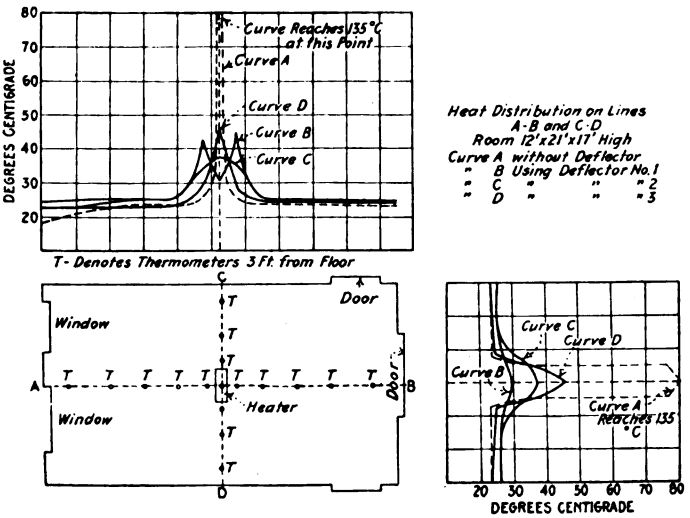


FIG. 5

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by 15 ft. and 9 1/2 ft. high with heater placed at the side of the room and using deflectors of various shapes.

Fig. 7 shows the dimensions of the living compartment in a submarine, and the results of tests of heating; and Fig. 8 shows the

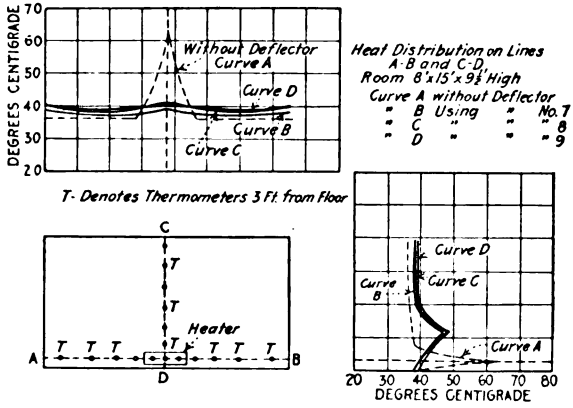


FIG. 6

dimensions of inner and outer staterooms and the results of tests and heating, and Fig. 9 shows comparative rise of inner and outer staterooms using enclosed and bare resistance type heating elements.

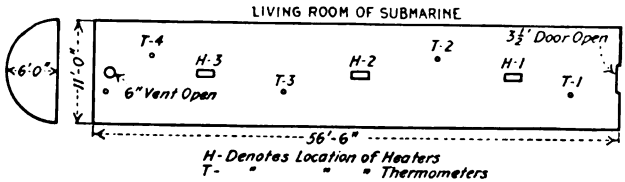


FIG. 7—HEATING TESTS ON SUBMARINE.

Temperatures in Centigrade

| Hour | Total watts | Outside | 1 | 2 | 3 | 4 | Av. | Increase above outside |
|---|---|---|---|---|---|---|---|---|
| 0 | 7600 | 8 | 16½ | 16½ | 17 | 16 | 16½ | 8½ |
| 2nd | 7600 | 8 | 18 | 18 | 20 | 17½ | 18½ | 10½ |
| 3rd | 7600 | 8 | 18 | 18 | 20 | 17½ | 18½ | 10½ |
| 6th | 7900 | 8 | 20½ | 20½ | 22 | 20 | 20½ | 12½ |

NOTE: Deflector No. 3 placed on 2 heaters at end of 3rd hour.

Fig. 10 gives a comparison between glow and convector types of heater as regards convected heat given off, and Fig. 11 shows the types and arrangement of deflectors used in obtaining the data for the curves herewith.

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From results of tests conducted during this investigation the following general results were obtained:

(1) For each 1000 cubic feet of space, 1500 watts input is required to maintain the temperature of air space of staterooms at 70 deg. fahr., based on the heater being installed in the center of the space, having an average height of 7.5 ft., and also based on replacing the entire space of air at outside temperature of 32 deg. fahr. every quarter of an hour.

(2) Where heaters are placed as in paragraph (1), but

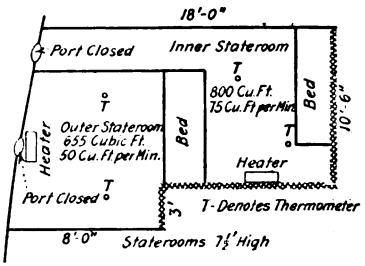


FIG. 8—HEATING TESTS IN STATEROOMS.

| Hour | Watts | Position of heater | Type of deflector | Temperature in Centigrade: Outside | Passage | Room average |
|---|---|---|---|---|---|---|
| | | | Inner Stateroom | | | |
| 2nd | 2760 | Center | None | 10 | 20 | 22 |
| 3rd | 2760 | " | " | 10 | 20 | 22½ |
| 5th | 2360 | " | No. 3 | 9 | 20 | 27½ |
| 3rd | 2260 | Side | None | 8 | 20 | 24 |
| 4th | 2260 | " | " | 8½ | 21 | 24½ |
| 7th | 2530 | " | No. 5 | 8 | 21 | 28 |
| | | | Outer Stateroom | | | |
| 2nd | 2040 | Center | None | 10 | 20 | 21 |
| 3rd | 2040 | " | " | 10 | 20 | 21½ |
| 5th | 1740 | " | No. 3 | 9½ | 20 | 27 |
| 3rd | 1650 | Side | None | 8 | 20 | 25½ |
| 4th | 1650 | " | " | 8½ | 21 | 25½ |
| 7th | 1840 | " | No. 5 | 8 | 21 | 29 |

installed with deflector of design No. 2, the input should be 1200 watts for 1000 cubic feet space.

(3) Where heaters are placed close to a bulkhead, without a deflector, the input should be 1300 watts.

(4) Where heaters are placed close up to a bulkhead, and a deflector of design No. 4 is used, the input should be 1100 watts.

(5) Where the space exceeds 20 ft. in either length or width, more than one heater should be selected.

It has been brought out by Dr. Langmuir that the heat loss by convection in small wires is nearly independent of the diameter,

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and it has been found in electric convectors that with the units at the same temperature, the amount of convected heat given off per watt input, increases when the diameter of the unit is decreased. However, as the unit must be of substantial con-

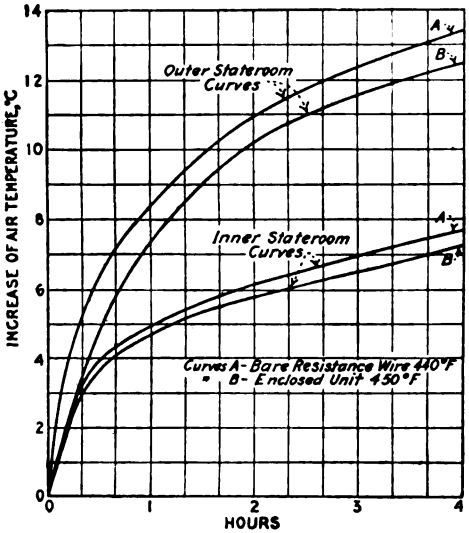


FIG. 9—COMPARATIVE TEMPERATURE RISE IN STATEROOMS.

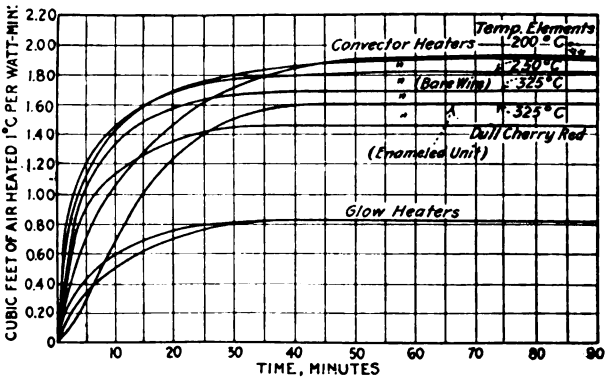


FIG. 10—AIR HEATED BY NATURAL VERTICAL DRAFT—COMPARISON BETWEEN GLOW AND CONVECTOR HEAT.

struction, the use of small diameter units is precluded, to some extent, by other considerations.

Convectors should, where possible, be fixed in or near the center of the room, but this is, as a rule, impracticable and it becomes

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necessary to secure them near a bulkhead. The effect of their position on the heating of a room is shown in Figs. 4, 5 and 6. When mounted near a bulkhead, the heaters should be heat-insulated fron the bulkhead and the back of the deflector should also be heat-insulated so that the losses through the walls can be kept low.

The investigation, the results of which are shown in preceding paragraphs, was conducted in order that the advantages of the best features of design and installation might be made use of to bring up the efficiency of the installation and minimize the ob-

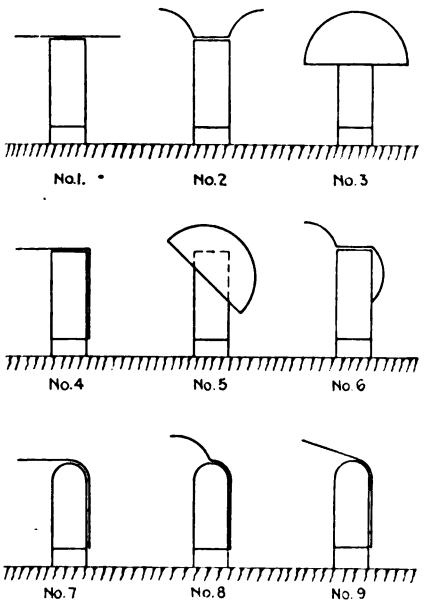


FIG. 11—DEFLECTORS USED.
Material No. 28 B. & S. gage sheet iron.

jection to the cost of electric air heating systems. The system of heating of spaces on shipboard which is now receiving most attention is a combination of steam and electric. Air for supply to spaces aboard ship is drawn in, by blowers from outside on the upper deck, through steam coils known as a thermo tank, and delivered to the spaces at about 50 deg. fahr. In each stateroom an electric convector heater is installed by which any additional increase in temperature is available to the occupant, and such temperature may be maintained by an automatic regulator thermostat installed in the convector circuit. This very conveniently re-

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moves the difficulty existing with the steam installation with its common piping system—that of the desirability of different temperatures for occupants of adjoining staterooms—and reduces to an inappreciable amount the additional expense of electric over steam heating.

The cost of generation of electricity aboard ships having boilers already installed for propulsion is about one cent per kilowatt-hour and in some cases is less than this value. At such a low cost of generation, the great objections met with on land installations of electric air heating where the cost is as high as fifteen cents, do not prevail.

The adaptability of electric air heating to the extension of original installations of steam heating is obvious, and investigation shows that the installation of greater generator capacity has in most cases been found unnecessary; this being because the heating load interferes very little with the cooking and lighting loads.

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*To be presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 23, 1914, under the auspices of the Committee on Use of Electricity in Marine Work.*

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*Subject to final revision for the Transactions.)*

# THE ELECTRICALLY DRIVEN GYROSCOPE IN MARINE WORK

BY H. C. FORD

ABSTRACT OF PAPER

The gyroscope when continuously driven by electric power may be used for various purposes, many of its applications having especial value in marine work.

Small gyroscopes are used to establish base lines for the measurement or control of angular motion. The gyro-compass makes use of the earth's daily rotation and consequent changing direction of gravity to secure a directive force a hundredfold greater and more accurate than that of the magnetic compass.

A general description is given of the gyro-compass as adopted by the United States Navy for use on all the battleships and submarine vessels. Many electrical and mechanical devices have been developed to perform the various functions whereby an instrument of great precision has been secured.

Large gyroscopes are made which are capable of counteracting enormous wave forces and completely stabilizing any ship against rolling in the heaviest seas.

UNTIL a few years ago the gyroscope was little known or heard of except as a child's toy, although as far back as 1852 its action was investigated by the French scientist Foucault, who published the results of his experiments in which he laid down very clearly the laws of its action.

His first law states that any gyro or spinning body possessed of three degrees of freedom, *i.e.*, free to rotate about a spinning axis and two other axes all normal to each other, will tend to maintain its axis of spinning fixed in space and may therefore be used to show the rotation of the earth. He also demonstrated that when a gyro was given a forced motion of rotation about one of the axes, the gyro would powerfully resist such force while at the same time tending to place its axis of spin in line with or parallel to the axis of the impressed force. This motion which takes place about an axis at right angles to that of the impressed force is known as gyroscopic precession and always occurs in such a manner as to bring the direction of spinning the same as that of the impressed force, and by the shortest path. In



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other words, if the spinning axis were horizontal and the axis of precession vertical, then the gyro, by virtue of the impressed force of the earth's rotation, would turn about in aximuth and place its axis of spin as far as possible in line with the earth's axis (*i.e.* upon the meridian) after the manner of a true compass. This strange resisting force with its unexpected motion of precession at a different angle and apparently unrelated to the impressed force, is in reality a simple and logical result of the inertia of the moving mass. Its explanation is well known and follows directly the application of Newton's laws.

It is not, however, the purpose of the writer to go into abstruse theoretical considerations. Suffice it to say that the law of precession explains fully the observed facts with regard to parallelism of the two axes, and is well illustrated in the accompanying figures, Nos. 1, 2 and 3, which show an ordinary gyroscopic top *A* mounted in a Cardan ring *B* by pivots *a*, the outer pivots *b* being supported upon a fork *C* rigidly mounted upon the base *D*. Suppose the wheel with all parts symmetrical, as in Fig. 1, is rotating clockwise, viewed from above, and we grasp the Cardan ring and depress it on axis *b* to position shown in Fig. 2. First it will be found that the Cardan ring is possessed of a quite remarkable amount of rigidity and opposes the forces tending to tilt it. However, as these forces are applied, and though the ring *B* is moved only slightly, yet the gyroscope is seen to immediately swing vigorously through a wide angle upon its axis *a* to the position also shown in Fig. 2. Upon lifting the Cardan ring the gyro will again be seen to swing vigorously in the opposite direction until arrested by the stop as shown in Fig. 3.

For nearly half a century after Foucault had demonstrated its action, the gyroscope was put to no practical use. The late American author and scientist Hopkins, whose writings were published for many years in the *Scientific American*, was the first to drive a gyroscope electrically. He was able to enlarge on Foucault's experiments and obtain much more persistent results with his continuously driven wheel.

The first serious application of the gyroscope in engineering work was by Obrey, an Austrian naval officer, who made use of the gyroscope to steer torpedoes. About 1903 Dr. Schlick, a German engineer, proposed the use of the gyroscope for stabilizing ships against rolling and built a number of experimental plants which were tried out with some little success. At about

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the same time Lewis Brennan brought general public attention to the gyroscope by his announcement of a railroad car that would maintain its equilibrium on a single rail. A car of this type was exhibited in this country in 1910 and the subject of monorail traction was much discussed in the press at the time in connection with the possibilities for high speeds which were claimed for this invention.

Practically all of the serious applications of the gyroscope, and by far the most important of its uses at the present time, have developed in marine work. These are, the steering of torpedoes, the use as a compass and the use for stabilizing and controlling the motions of ships, the last two of which will be discussed more fully.

Several minor applications have been made, such as (1) stabilizing of various instruments, telescopes, etc. against oscillations when mounted on a rolling ship; (2) stabilizing of a pendulum carrying a pen for recording the angles of roll and pitch of a ship; and, (3) stabilizing a horizontal mirror for use as an artificial horizon in taking observations at sea. Some very valuable results have been accomplished along these lines, but the limits of the present paper will not permit of more than a brief mention. Various attempts have also been made to stabilize a body with three degrees of freedom for use in the direct determination of latitude and longitude, but so far as is known, without practical success.

Fig. 4 shows a form of telescope used on board ship for obtaining bearings of distant objects, which has been stabilized by means of gyroscopes so that it is entirely unaffected by motions of the ship in any direction.

Fig. 5 shows one of several types of apparatus which have been constructed for recording the rolling and pitching motion of a ship upon a moving sheet. In the instrument here shown, records of the azimuth as well as various time markings are made simultaneously upon the same record sheet.

Errors are frequently introduced in navigation when measuring the altitude of a heavenly body above a false horizon caused by mist or by the mirage effect of the heated air on a tropical sea. Very frequent observations of the sun or heavenly bodies could be taken were it not that the horizon is obscured by low-lying banks of fog or darkness.

Fig. 6 illustrates a gyroscopic artificial horizon which provides a means for eliminating these errors in observation and

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makes it possible to measure accurately the altitude of any heavenly body that can be seen, whether or not the horizon is obscured.

The automobile torpedo, as is well known, depends upon a gyro steering gear for its directive power and would in fact be utterly ineffective for its purpose without such a device. The importance of the torpedo in warfare is of course recognized, so that the great value of this application of the gyro needs no further comment.

The gyro compass shown in Fig. 7 is now being installed upon all of the battleships and submarines of the United States Navy, where it is depended upon absolutely for use under battle conditions where the magnetic compass could not possibly be employed, due to the large masses of magnetic material constantly being moved about in proximity to the compass. As an instrument of navigation the gryo compass has also proved of great accuracy and value in enabling the ship to be held steadily upon its course irrespective of wind, sky or sea. The foreign navies are also rapidly adopting the gyro compass and it seems certain that its use on all of the larger steamships and ocean liners will be found in a few years when its great advantages have become more widely known.

The very high development of the gyro compass during the past few years has been largely due to the efforts of a pioneer in the electrical art, Mr. Elmer A. Sperry, whose long and interesting experience with gyroscopic phenomona and belief in their engineering possibilities led him to devote practically all of his time to its development.

It has been the privilege of the writer to be associated with Mr. Sperry for several years past in this work, during which time a plant has been organized and equipped for the design and manufacture of many forms of gyroscopic apparatus.

A number of workers abroad have also been laboring with great persistence and some degree of success to solve the many physical problems involved in translating the idea of Foucault into concrete terms of steel and bronze which will function under the extremely severe conditions on shipboard.

The nature of the problem is indicated when one realizes that the gyro compass is so sensitive that it responds instantly and with the highest degree of accuracy to the very slowly impressed angular motion in space about the earth's axis four thousand miles distant, while at the same time it remains indifferent

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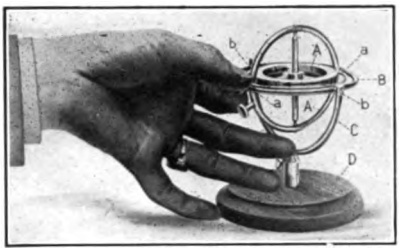


FIG. 1 [FORD]

Cardan-Mounted Gyro for Demonstrating Gyroscopic Precession.

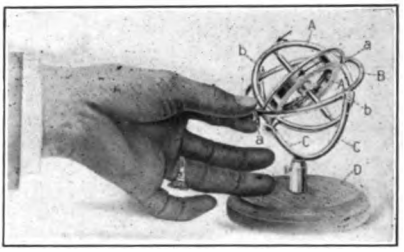


FIG. 2 [FORD]

Precession Carrying the Upper End of Shaft to the Left by Tilting the Cardan Ring Downwardly.

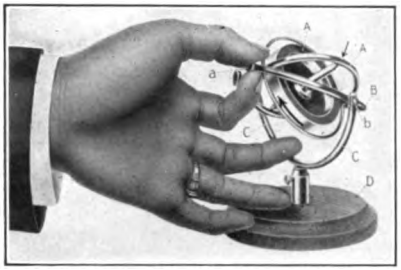


FIG. 3 [FORD]

Precession Carrying the Upper End of Shaft to the Right by Tilting the Cardan Ring Upwardly.

FIG. 4 [FORD]

Telescope Stabilized by Gyros.

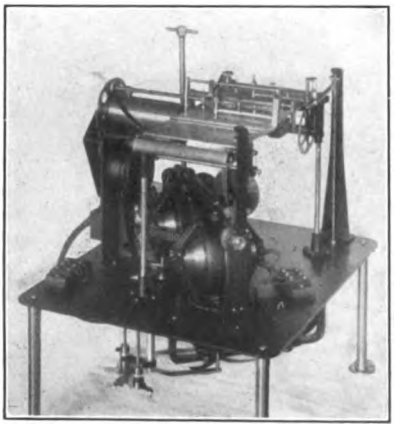

FIG. 5 [FORD]

Instrument for Recording the Rolling, Pitching and Yawing of Vessels.

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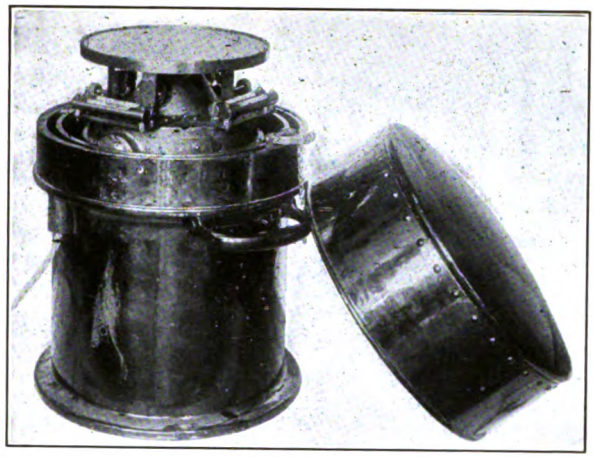

FIG. 6 [FORD]
Gyroscopic Artificial Horizon.

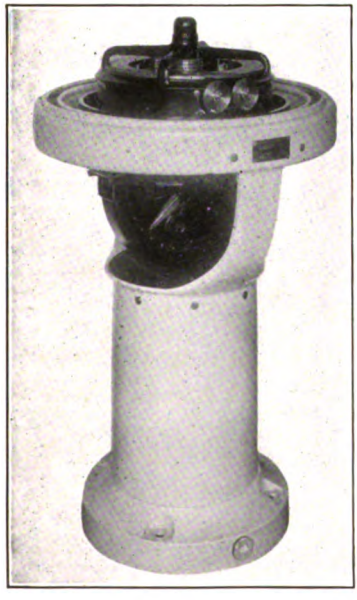

FIG. 7 [FORD]
Master Compass with Covers Removed.

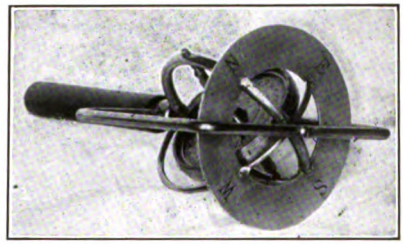

FIG. 8 [FORD]
Model for Demonstrating the Action of the Gyro Compass.

FIG. 10 [FORD]
Complete Equipment for a Gyro Compass Installation on a Battleship.

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to the angular movements of the ship several hundred times greater in intensity.

In view of the extensive use of the gyro compass and the nature of the problems involved in its development, it may be of interest to look into the theory of its action somewhat briefly and then to note some of the many special construction details and various electrical devices employed in this highly organized instrument.

Fig. 8 shows a small device which may be used to demonstrate the action of precession in the gyro compass. In this device we have a small disk marked with the cardinal points to represent a compass card and mounted upon a ring swiveled to rotate on a vertical axis within a hand-supporting frame. The ring carries a wheel which spins upon a horizontal axis fixed in the ring parallel to the NS line of the compass card. If the device is held extended in the hand while the demonstrator turns slowly on his heel toward the left, we may consider his body as the axis of an imaginary earth and his head as the virtual north pole, since his rotation would always be easterly.

If the device is extended with the axis of the card perpendicular to the body at the waist line, the compass may be considered as located approximately at the equator. If held opposite the shoulder, with the axis of the compass card or handle making an angle of 45 deg. with the body, the compass would be represented in operation at latitude 45 deg. north.

Now when the wheel has been made to spin in a clockwise direction viewed from the south side of the card, if the device is carried about in the hand as above, the card will immediately orientate or turn on its axis to bring the north side toward the virtual north pole.

If the demonstrator should reverse his direction of rotation and turn toward the right, which would now represent east, we should have to consider that the north pole had been shifted to his feet, and if the little model is a true compass it should also reverse its direction and point to the new pole. This is what actually occurs, for the gyro compass not only holds to the meridian when placed thereon, but is actually possessed of a powerful north-seeking tendency many times greater than that of the magnetic needle.

The above demonstrates the elementary action of the gyro compass on an imaginary earth, the length of whose day is about twenty-four seconds. Under such conditions this little compass is ideal in its simplicity.

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When, however, we are considering an instrument of precision, for actual use on a ship rolling, pitching and yawing in a heavy sea, or manoeuvering at various speeds in every possible direction, the matter of picking out this demonstrator who will keep his body parallel to the earth's axis under such conditions and rescue a struggling directive force from the waves, is a somewhat larger contract.

As a matter of fact, many and serious are the mechanical and theoretical problems which had to be solved in producing a practical compass for navigation. For example, when mounted on a ship steaming rapidly north, say, the gyro axis does not point true north, but has a certain deflection, for the reason that the actual motion in space is no longer due easterly, but is about a resultant axis somewhat to the westward of the earth's axis. The amount of this deflection, which is a variable, depending upon the speed, course and latitude of the ship, has been exactly determined for all conditions.

In the Sperry compass a device is employed which corrects for the above factors and automatically introduces this correction into the compass readings, which are therefore always made accurately upon the meridian. Other special mechanical devices are employed for the following purposes, among others:

a. To provide a substantial mounting for the gyro element with the highest degree of sensitiveness.

b. To damp oscillations in azimuth.

c. To compensate various acceleration pressures.

d. To prevent errors caused by retardation of the wheel.

e. To set the compass quickly on the meridian even when the direction is unknown.

f. To prevent errors due to persistent oscillations in certain oblique planes.

g. To admit of determining the speed of the wheel by observation.

Space will not permit of a further study of the many theoretical problems involved nor of a detailed description of all the mechanical devices employed in this solution.

The general arrangement of parts constituting the Sperry gyro compass is shown in Fig. 9, which for greater clearness in illustrating the various functions has been simplified by the omission of electrical circuits and minor details.

The gyroscope wheel is mounted to rotate on a horizontal shaft $A$ within the casing $B$, which is pivoted on the horizontal

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axis $C$ through its center of gravity and carried by the frame or vertical ring $D$.

The ring $D$ is suspended by a torsionless strand $E$ and guided by bearings $F$ and $F'$ to allow a free oscillation of limited amount about its vertical axis within the frame or "phantom" $G$, so called because of its characteristic action as a "shadow" in following up each motion of the ring $D$. The phantom $G$ has a hollow stem $H$ to which the strand $E$ is attached at its upper end, and the stem forms a journal for rotation in azimuth with respect to the supporting base frame $J$.

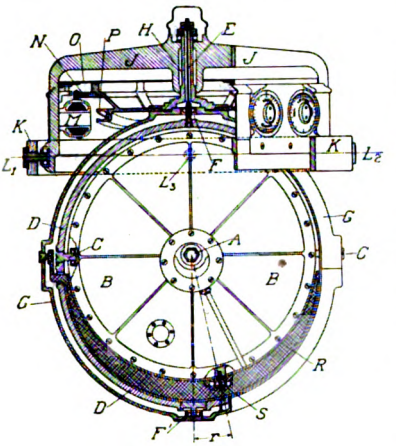


FIG. 9—METHOD OF MOUNTING THE DIRECTIVE ELEMENT

The frame $J$ is mounted to swing in the binnacle by the usual Cardan suspension, consisting of the ring $K$ and suitable bearings $L1$ $L2$, $L3$ and $L4$, the last not shown.

The frame $J$ carries a "follow-up" motor $M$, driving a master gear $N$, forming a rigid part of the phantom $G$, whereby the latter is positively driven in azimuth to respond to any movement of ring $D$.

The ring $D$, which with the wheel casing is termed the "element," carries a pair of electrical contacts in the form of trolley wheels, which cooperate with stationary contacts mounted upon the phantom $G$ for the purpose of controlling the follow-up motor $M$, the electrical connections not being shown in the figure.

The power-driven phantom $G$ is thus automatically controlled so as to respond instantly to all movements of the sensitive element, and in fact to all relative movement in azimuth between the ship and the gyro.

This characteristic of the phantom enables it to be used for various important functions, namely, to carry the scale or card $O$ and a cam $P$ forming part of the automatic correcting device. The power drive is also utilized in operating the transmitter for the repeater instruments, and in overcoming friction of the slip rings needed to carry current to the gyro.

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Since the phantom $G$, though at all times rigidly anchored to the binnacle, stands in practically constant relation to the sensitive element as regard motion about the vertical axis, but is nevertheless entirely separate therefrom, it serves as an anchorage for producing stresses to restrain and correct the movements of the sensitive element. This is accomplished by means of a yielding connection between the phantom $G$ and the gyro case $B$, in the form of a pendulum or bail $R$, supported by and forming a part of the phantom. The point of attachment $S$ to the gyro casing is located in a certain position eccentric to both the vertical and horizontal axes of the gyro. By this means several most important results are obtained, including positive orientation and the prevention of oscillation.

The complete electrical equipment of the compass system which will now be considered comprises:

1. A voltage regulator of special design.
2. A three-phase a-c. generating set.
3. A 20-volt d-c. generating set.
4. A d-c. emergency service.
5. An alarm system.
6. An automatic control and protective system.
7. Specially designed controlling switches.
8. The gyro motor.
9. A servo motor or follow-up system.
10. A secondary transmitting and receiving system.

Fig. 10 illustrates the various parts of the Sperry gyro compass system for use on a battleship. The master compass and controlling apparatus are installed in a protected portion of the ship behind heavy armor. The repeater compasses are mounted at various points about the ship at the different steering stations. On a battleship, for instance, repeaters are supplied at the main steering platform, others on the bridge for taking bearings, one in the conning tower for steering during battle, one in the steering engine room at the stern of the ship, and in some cases one or more additional repeaters in ships provided with additional steering stations.

The compass is also used in connection with various other instruments for obtaining and recording various data.

A most important use of the gyro compass is on submarine boats which derive their power, when submerged, from storage batteries, the voltage of which varies at times from as high as 160 volts down to 100 volts at the end of a long run. An economical form of voltage regulator has been devised for such service.

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The problem of accelerating and driving the heavy balance wheel (the compass wheel weighs about 45 lb. or 20.4 kg.) at a velocity of about 8600 rev. per min. required the design of a special form of generator, three-phase current at 90 volts being used. The characteristics of the generator allow of the wheel being thrown directly upon the line and brought up to full speed automatically in about thirty minutes without attention on the part of the operator and without the use of excessive current. This machine, shown in the background of Fig. 10, has a capacity of three amperes per phase, but is ordinarily run under a load of 0.9 amperes.

The 20-volt d-c. dynamotor also shown in Fig. 10 is used in supplying energy to the servo motor follow-up system and for operating the secondary or repeater compass system. No special features of design were necessary other than to meet the usual requirements on ship board as to commutation, rating, accessibility, etc. In battleship equipments, both of the above generating units are ordinarily supplied in duplicate.

An emergency direct-current service is provided by the employment of a 20-volt storage battery which is kept floating upon the line at all times. This provides energy for operating the follow-up system of the compass whenever the ship's service has failed. During such times the gyro wheel, on account of its great inertia and ease of operation in vacuum, will remain spinning and will give ample directive power for an hour or more after the power has been shut off, so that the compass is rendered fully effective under all such conditions. This constitutes a unique and extremely valuable feature of the Sperry compass.

An independent six-volt battery and alarm bell are employed to notify the attendant promptly of any interruption of current or failure in operation of various parts of the system which would be likely to cause errors in the compass readings, so that the same may be corrected without delay. A trip relay is provided which keeps the bell ringing until the attendant has corrected the difficulty and reset the trip.

A reverse current relay is provided for disconnecting the direct-current dynamotor from the storage battery and line upon failure, or any material reduction in voltage of the generator or ship's supply line, and for connecting the generator in again when voltage has been restored to normal. This of course prevents the rapid discharge of the storage battery in driving the generator.

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Especially designed switches and controlling apparatus are provided, which include a small and compact switch for throwing both the voltmeter and ammeter at once upon any one of a number of different circuits or phases. These switches are of the rotary or controller type and are enclosed in gas-tight cases to prevent danger of explosions when used in submarines.

The gyro motor is of the three-phase induction type, the squirrel-cage secondary forming a rigid part of the inner rim of the revolving wheel shown in Fig. 11.

On account of the high speed of the rotation, wheels have to be given a very careful running balance, which is accomplished by the use of various size studs threaded into holes at the periphery of the wheel on each side.

The stator also shown in Fig. 11 is mounted on one side of the main vacuum casing containing the wheel. A spiral line is painted on the wheel which, when observed through a window in the casing by means of a stroboscope, enables one quickly to determine the speed of rotation.

The servo motor or follow-up system forms an important part of the gyro compass and performs three functions, of which the first is to shield the gyro from all external forces and friction. This is accomplished by the method of carrying the supporting filament, and all guiding bearing shaving to do with the sensitive element, within an outer frame known as the phantom (Fig. 12), which completely shields the element from all disturbing external forces.

The suspended mass of the sensitive element, which, including the wheel casing and the vertical supporting ring, weighs about seventy-five pounds, is by the above means rendered actively sensitive to a force couple of 1/4500 in-lb., which represents a force of less than one-fourth-millionth part of its own weight acting at a radius of one foot. This degree of sensitiveness is actually measurable in the operation of the compass, which is thought to be somewhat remarkable in this respect.

A second function of the servo motor, which in the gyro compass is known as the " azimuth motor," is to operate the transmitter for sending out indications to any number of repeater compasses located at distant parts of the ship. The main azimuth scale of the compass is also carried on the power-driven member.

The third function of the azimuth motor is to operate the

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correction device before mentioned, which by means of cams solves a trigonometric equation involving the factors of speed, latitude and heading of the ship, and automatically introduces the proper correction into the compass readings, which are therefore maintained accurately upon the meridian. Fig. 13 shows the front of the correction device and dials which are set at the proper speed and latitude.

The azimuth motor with its reduction gearing is shown in Fig. 14, and is provided with ball bearings throughout. An inertia brake consisting of a balance wheel mounted and driven by friction on the armature shaft serves to damp the oscillations or hunting of the azimuth motor, while offering no resistance to continuous motion.

The secondary transmission system comprises a contact making transmitter and six-pole step-by-step motor connected by three circuits having a common return wire. The transmitter (Fig. 15) is provided with three pairs of tungsten make-and-break contacts which are operated by cams. The construction of the repeater system is such that the motor may be driven at speeds as high as 1000 rev. per min., or 100 cycles per second, without getting out of step.

The repeater motor is geared to give six steps for each indicated degree in azimuth and the repeater compass instantly follows all changes of the master compass for every movement of the ship. The repeaters are provided with compass cards made of translucent material to permit of illumination from within.

A manually operated transmitter, or synchronizer, is used for setting the distant repeaters into agreement with the master compass in connection with a magnetic stop for each motor by means of which the repeaters are first collected upon a common reading and then brought at once to read with the master which is then thrown into circuit.

The exceptionally fine results obtained with the gyro compass here described have fully justified the long and painstaking efforts that have been expended in its design and in the practical solution of the many problems met at various stages of its development and in actual use at sea.

When subjected to the most drastic tests, far greater in severity than any actual conditions found on ship board, the compass continues to hold to the meridian within a fraction of a degree. In fact, every compass before being accepted by our Government has to pass through a series of such tests lasting several weeks,

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during which time the maximum error must not exceed ½ deg. in azimuth when swung continuously for six days at a time under conditions of rolling, pitching and yawing of an artificial ship.

It should of course be understood that under similar conditions on board a battleship or submarine the magnetic compass would be almost if not entirely useless. Even under the best of conditions, navigation of a steel ship by magnetic compass entails a large amount of extra work with considerable liability of error in applying variation and deviation corrections of various amounts, plus or minus. With the gyro compass described, all readings are made exactly upon the meridian and the navigator is always sailing on true courses. The quick and accurate indications of the compass for the slightest deviation or yawing of the ship has enabled much straighter courses to be steered, with a resulting saving in fuel and increased speed. For intricate manoeuvering in battle practise, the ship may be controlled perfectly from various protected steering stations and the master compass is completely shielded from the fire of the enemy and from the shock of gun fire.

In submarines the gyro compass enables an accurate course to be laid when running submerged so that after obtaining the bearing of the target from a great distance the submarine may approach, submerged, to within a short distance and fire its torpedoes accurately.

From an instrument having a degree of sensitiveness to force couples measured by one-four-millionth part of its own weight it is rather a long jump to consider another type of gyro possessed of many tons of stored energy which may be harnessed and made to work not only to hold a mammoth ship against rolling in high seas but actually to roll the ship for the purpose of sliding off a sand bar or breaking through an ice floe.

Gyros of this type have already been built, tested and thoroughly investigated and a gyro of thirty tons weight capable of exerting a force couple of over four million pound-feet is now under construction for stabilizing the S. S. *Ashtabula* used as a car ferry on Lake Erie.

In two papers read before the Institute of Naval Architects and Marine Engineers in November 1912 and December 1913, Mr. Sperry has treated very ably and comprehensively the subject of stabilizing ships and has made some striking comparisons which show his valuable contribution to the art in the

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" active " type of gyro. In the last paper referred to are shown characteristic rolling and damping curves for ships equipped with active gyros when subjected to various wave impulses and frequencies. These curves, some of which are here reproduced in Fig. 16, were obtained from a model ship pendulum, the dimensions of which were adjusted to correspond to a 19,000-ton ship at the linear ratio of 1:30.

The stabilization is practically complete, as indicated by the curves in Fig. 16. Early in this work observations were made indicating that the stabilization was complete even when the wave increments received from the sea were greater than the theoretical power of the gyros mounted in the ship.

The work with the stabilizer has shown that it is perfectly easy to stabilize against all wave increments received by the ship from the sea which are equal or less than the stabilizing capacity of the gyro equipment. Stabilization is so complete under these conditions that interest in this part of the performance has been transferred to investigations of the region where the wave increments are actually in excess of the stabilizing capacity.

The curves in Fig. 16 are among the results obtained in this connection and it will be seen by carefully scrutinizing the cards that none of the curves are taken where the wave increments are not larger than the roll-quenching increment, and even under these conditions the stabilizing is practically complete for practically all the wave periods.

Practical data of great value were obtained from the construction of an active gyro plant which was tested out repeatedly on the U. S. S. *Worden* during the summer of 1912. This plant was the largest gyro installation ever built and consisted of two gyros weighing about three tons each which were operated actively by use of a precession engine.

The gyros were automatically controlled so that they responded instantly to all wave increments encountered, whether in harmony with the period of the ship or not.

Fig. 17 shows one of the *Worden's* gyros bolted on a heavy base plate while under test at the Brooklyn Navy Yard. The base was loaded with pig iron, which, with the load of the gyro and precession engine, brought the total weight up to over thirty tons. The gyro very effectively demonstrated its power by actually lifting this heavy load, tilting the whole base plate up on edge and rocking it back and forth as the gyro was precessed.

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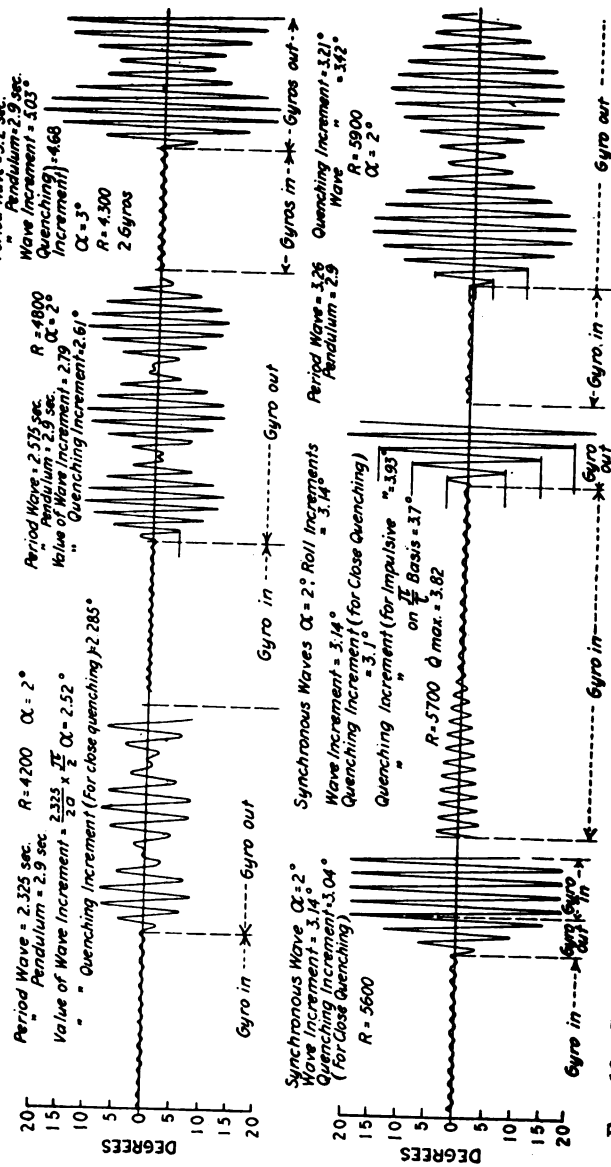
Period Wave = 2.325 sec.
" Pendulum = 2.9 sec
Value of Wave Increment = 2.325/20 × π/2 α = 2.52°
" " Quenching Increment (For close quenching) = 2.285°
R = 4200 α = 2°
Gyro in
Gyro out
DEGREES
Synchronous Wave α = 2°
Wave Increment = 3.14°
Quenching Increment = 3.04°
(For Close Quenching)
R = 5600
Period Wave = 2.575 sec.
" Pendulum = 2.9 sec.
Value of Wave Increment = 2.79
" Quenching Increment = 2.61°
R = 4800
α = 2°
Synchronous Waves α = 2°. Roll Increments = 3.14°
Wave Increment = 3.14°
Quenching Increment (for Close Quenching) = 3.1°
Quenching Increment (for Impulsive " = 3.93° on π/2 Basis = 3.7°
R = 5700 Φ max. = 3.82
Period Wave = 3.26
Pendulum = 2.9
Quenching Increment = 3.21°
Wave " = 3.42°
R = 5900
α = 2°
Gyros in
Gyros out
Gyro in
Gyro out
Period Wave = 3.2 sec.
" Pendulum = 2.9 sec.
Wave Increment = 3.03°
Quenching Increment = 4.68
α = 3°
R = 4.300
2 Gyros

FIG. 18—CURVES SHOWING THE PERFORMANCE OF THE "ACTIVE" TYPE OF GYROSCOPE IN STABILIZING A PENDULUM SHIP MODEL AGAINST WAVE FORCES GREATER THAN THE THEORETICAL POWER OF THE GYRO

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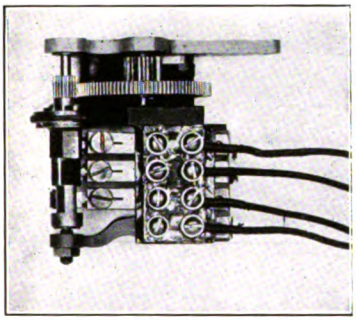

FIG. 15 [FORD]

Transmitter for Operating Secondary or Repeater Compasses.

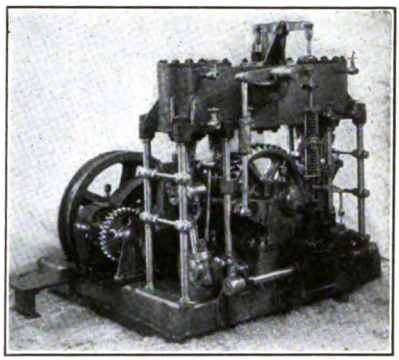

FIG. 18 [FORD]

The Precession Engine.

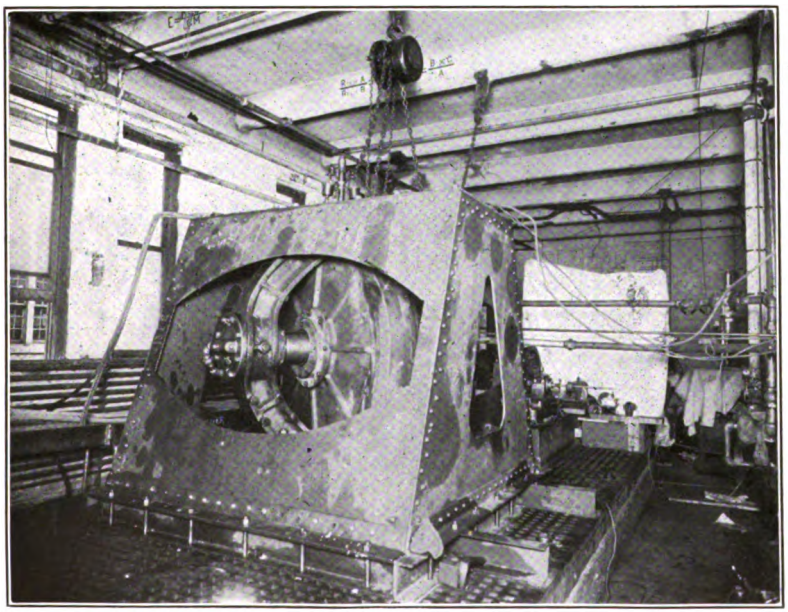

FIG. 17 [FORD]

One of the Two Large Gyros of the U. S. S. *Worden* while under Preliminary Tests at the Navy Yard, New York.

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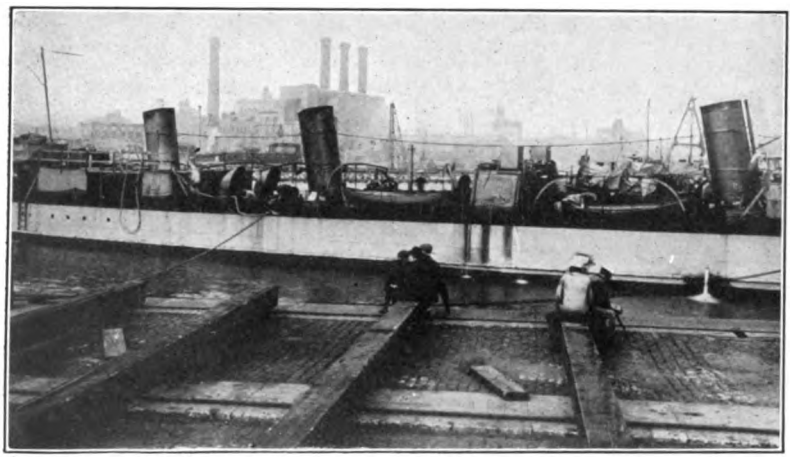

FIG. 19 [FORD]

The U.S.S. *Worden* at Dock.

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Fig. 18 shows the precession engine, and Fig. 19 shows the gyro equipment mounted aboard the *Worden* ready for the sea trials.

The results prove conclusively that the active type of gyroscope as applied the control of a ship's rolling motion is of vastly greater efficiency and economy than any other form of stabilizer yet proposed. The efficiency is demonstrated by the action of carefully calculated scale models and is completely verified by the long-continued performance at sea of the gyro plant on the *Worden*. The economy is evident from a comparison of the space and weight required in an installation of the active gyro relative to that required by the most effective form of water damping tanks or other stabilizing means.

Careful calculations show that an active gyro plant for stabilizing the S. S. *Ashtabula* will require less than one-tenth the space and weight which would be necessary for equivalent stabilizing with the best-designed water pendulum.

The results further show that it is now possible to completely stabilize any ship against rolling by means of an active gyroscope, requiring a very small percentage of the weight and space available in the ship. This work has opened up a wide field of usefulness in the application of the gyroscope.

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*To be presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 24, 1914, under the auspices of the Electrophysics Committee.*

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(*Subject to final revision for the Transactions.*)

# THE SPHERE GAP AS A MEANS OF MEASURING HIGH VOLTAGE

BY F. W. PEEK, JR.


## Abstract of Paper

A gap method of measuring high voltage is desirable in certain tests because a gap measures the maximum point of the voltage wave.

The needle gap is unreliable, and is subject to large corrections due to humidity, etc. The sphere gap is free from complicated corrections and the curve is subject to calculation. Wherever voltage is measured by a gap, correction must be made for air density—that is, altitude or barometric pressure, and temperature. The laws for this correction have been deduced for the sphere gap, from tests, over an air density range equivalent to that from sea level to 18,000 ft. elevation. An equation is given for calculating sphere spark-over curves for various spacings, radii, air density, etc.

Standard measured curves for convenient sizes of spheres at sea level are given for practical use, as well as a table for applying these curves to any altitude. The altitude correction may be made very accurately to the standard curve, either by applying the calculated correction constant or by applying the correction factor given in the tables.

*The complete standard curves should not be calculated when reliable measured curves are available.*

The effect of high frequency and impulse voltages are discussed. In making measurements certain precautions are necessary for accuracy, as well as for protection of apparatus. These precautions are discussed and test results are given.


A GAP method of measuring high voltages is often desirable in certain commercial and experimental tests. As a gap measures the maximum point of the voltage wave it is therefore used in many insulation tests where breakdown also depends upon the maximum voltage point. In most commercial tests an accuracy of one or two per cent is sufficient. A greater accuracy can be obtained with the sphere gap for special work where proper precautions are taken.

## The Needle Gap

The needle gap is unreliable at high voltages because, due to the brush and broken-down air that precedes the spark-over, variations are caused by humidity, oscillations, and frequency.[1]

1. Discussion, F. W. Peek, Jr., A. I. E. E., Feb. 1913. *G. E. Review*, May, 1913.



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The needle gap is also inconvenient because needles must be replaced after each discharge; the gap becomes very long at high voltages, and the calibration varies somewhat with the sharpness of the needle.

The effect of humidity is shown in Fig. 1, where it can be seen that a higher voltage is required to spark over a needle gap when the humidity is high than when it is low. (Curves of Fig. 1, are intended only to illustrate this effect). It is probable that the corona streamers in humid air cause a " fog ", and then agglomerate the water particles, which, in effect, increase the size of the electrodes.

All spark curves of whatever form of gap must be corrected for air density; that is, altitude and temperature. For *low voltages* the spark-over voltage of the needle gap decreases approximately as the air density. At higher voltages the effect becomes erratic, probably due to humidity.

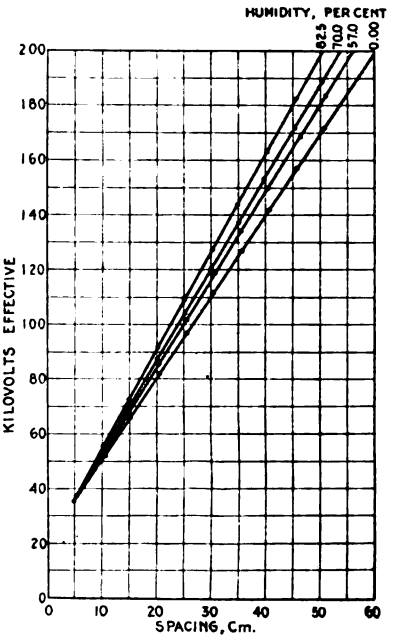


FIG. 1—APPROXIMATE NEEDLE GAP CURVES FOR DIFFERENT RELATIVE HUMIDITY

## THE SPHERE GAP

The voltage required to spark over a given gap between spheres increases with the diameter of the sphere. Corona cannot form on spheres, or rather, the spark-over point and corona point are coincident if the spacing is not greater than the diameter of the sphere. Practically a spacing as great as three times the radius may be used without appreciable corona. The voltage limit of a given sphere in high-voltage measurements is thus reached when a gap setting greater than three times the radius is required. A larger sphere should then be used. With this space limit, the first evidence of stress is complete spark-over; corona can never form, and all of the undesirable effects and variables due to brush discharge and broken-down air are eliminated. Humidity has no measurable effect.

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The space factor is relatively small. Several thousand measurements may be made without repolishing. The curve may be calculated. The only correction is the air density correction. This has been investigated and the results are given below. The correction is quite simple. Fig. 2 gives typical sphere-gap curves for both spheres insulated and for one sphere grounded. Tables I to V give spark-over curves for 6.25, 12.5-, 25-, 50 and 100-cm spheres at sea level, (25 deg. cent., 76 cm. barometer). $\delta = 1$. (See Note 2).

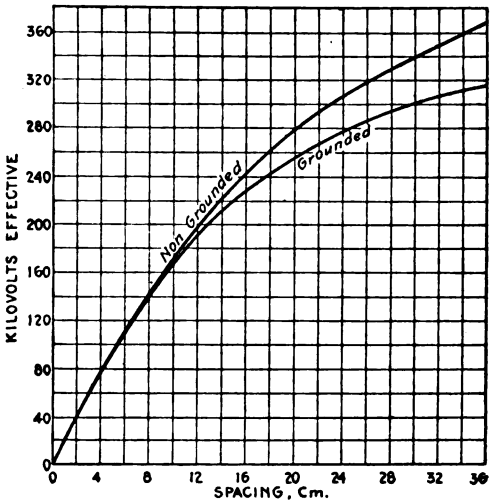


FIG. 2—SPARK-OVER CURVES
25 cm. diam. spheres

*Calculation of Curves*: The gradient or stress on the air at the sphere surface, where it is greatest, is found mathematically:

$$g = \frac{e}{x} f \text{ kv. per cm.}$$

where $e$ is the applied voltage in kilovolts, $x$ is the spacing in centimeter, $f$ is a function of $\frac{x}{R}$, and $r$ is the radius of the sphere in centimeters.

2. *The Calibration of the Sphere-Gap Voltmeter*, Chubb and Fortescue, A. I. E. E., Feb. 1913. Discussion F.W. Peek, Jr., A. I. E. E., Feb. 1913. "The Sphere Gap as a Means of Measuring High Voltage." F. W. Peek, Jr., *G. E. Review*, May, 1913.

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TABLE I

SPHERE-GAP SPARK-OVER VOLTAGES
6.25-cm. DIAMETER SPHERES.

| Spacing | | Kilovolts effective | |
|---|---|---|---|
| cm. | in. | Non-grounded | Grounded |
| 0.5 | 0.197 | 12 | 12 |
| 1. | 0.394 | 22.5 | 22.5 |
| 1.5 | 0.591 | 31.5 | 31.5 |
| 2 | 0.787 | 41. | 41. |
| 3 | 1.181 | 57.5 | 56. |
| 4 | 1.575 | 70.5 | 66. |
| 5 | 1.969 | 81. | 73. |
| 6 | 2.362 | 89. | 79. |
| 7 | 2.756 | 96. | 83. |
| 8 | 3.150 | 102. | 88. |
| 9 | 3.543 | 107. | 90.5 |
| 10 | 3.937 | 110 | 93. |

Each point is the average of five readings. The average variation between maximum and minimum for a given setting is less than 0.5 per cent.

TABLE II

SPHERE-GAP SPARK-OVER VOLTAGES.
12.5-cm. DIAMETER SPHERES.

| Spacing | | Kilovolts effective | |
|---|---|---|---|
| cm. | in. | Non-grounded | Grounded |
| 0.25 | 0.098 | 6.5 | 6.5 |
| 0.50 | 0.197 | 12. | 12. |
| 1 | 0.394 | 22 | 22. |
| 1.5 | 0.591 | 31.5 | 31.5 |
| 2 | 0.787 | 41 | 41. |
| 3 | 1.181 | 59 | 59. |
| 4 | 1.575 | 76 | 75 |
| 5 | 1.969 | 91 | 89 |
| 6 | 2.362 | 105. | 102 |
| 7 | 2.756 | 118. | 112 |
| 8 | 3.150 | 130 | 120 |
| 9 | 3.543 | 141. | 128 |
| 10 | 3.937 | 151. | 135 |
| 12 | 4.72 | 167. | 147 |
| 15 | 5.91 | 188 | 160 |
| 17.5 | 6.88 | 201 | 168. |
| 20. | 7.87 | 213. | 174. |

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Then $$g_s = \frac{e_s}{x} f \text{ kv. per cm.}$$

where $e_s$ is the spark-over voltage and $g_s$ is the apparent strength of air.

$f$ is found mathematically and tabulated in Table VI[3] for the non-grounded and grounded cases. For the non-grounded case it

TABLE III

SPHERE-GAP SPARK-OVER VOLTAGES.

25-cm. DIAMETER SPHERES

| Spacing | | Kilovolts effective | |
|---|---|---|---|
| cm. | in. | Non-grounded | Grounded |
| 0.5 | 0.197 | 11 | 11 |
| 1. | 0.394 | 22 | 22 |
| 1.5 | 0.591 | 32 | 32 |
| 2. | 0.787 | 42 | 42 |
| 2.5 | 0.983 | 52 | 52 |
| 3 | 1.181 | 61 | 61 |
| 4. | 1.575 | 78 | 78 |
| 5 | 1.919 | 96 | 94 |
| 6 | 2.362 | 112 | 110 |
| 7.5 | 2.953 | 135 | 132 |
| 10. | 3.937 | 171 | 166 |
| 12.5 | 4.92 | 203 | 196 |
| 15. | 5.91 | 230 | 220 |
| 17.5 | 6.88 | 255 | 238 |
| 20. | 7.87 | 278 | 254 |
| 22.5 | 8.85 | 297 | 268 |
| 25. | 9.83 | 314 | 280 |
| 30. | 11.81 | 339 | 300 |
| 40. | 15.75 | 385 | 325 |

was found experimentally that $g_s$, the apparent surface gradient at spark-over, increased with decreasing radius of sphere, as $g_v$ for corona on wires increases for decreasing radius of wire. For a given size of sphere, $g_s$ is practically constant independent of spacing, between the limits of $x = 0.54\ \sqrt{R}$ and $x = 2\ R$.

3. See *Law of Corona III*, F. W. Peek, Jr., A.I.E.E., June, 1913. G. R. Dean, *G. E. Review*, March, 1913; *Physical Review*, Dec. 1912 and April 1913. Russel—*Philosophical*, May 1906.

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The *average* gradient between these limits of separation is[4]

$$g_s = 27.2 \left(1 + \frac{0.54}{\sqrt{R}}\right) \text{kv. per cm. max.} \qquad (1a)$$

$$g_s = 19.3 \left(1 + \frac{0.54}{\sqrt{R}}\right) \text{kv. per cm. eff. sine wave.} \qquad (1b)$$

TABLE IV

SPHERE-GAP SPARK-OVER VOLTAGES.
50-cm. DIAMETER SPHERES

| Spacing | | Kilovolts effective | |
|---|---|---|---|
| cm. | in. | Non-grounded | Grounded |
| | | * | |
| 2 | 0.787 | 40 | 40 |
| 4 | 1.575 | 76.5 | 76 |
| 6 | 2.362 | 115.5 | 112 |
| 8 | 3.150 | 149 | 145 |
| 10 | 3.937 | 189 | 185 |
| 12 | 4.72 | 224.3 | 220 |
| 14 | 5.51 | 255.5 | 250 |
| 16 | 6.30 | 285 | 275 |
| 20 | 7.87 | 335 | 320 |
| 25 | 9.83 | 393 | 377† |
| 30 | 11.81 | 445 | 420 |
| 35 | 13.80 | 493 | 456 |
| 40 | 15.75 | 537 | 489 |
| 45 | 17.72 | 573 | 516 |
| 50 | 19.19 | 605 | 541 |
| 55 | 21.65 | 633 | 561 |
| 60 | 23.62 | 660 | 579 |
| 65 | 25.60 | 684 | 594 |
| 70 | 27.56 | 705 | 608 |
| 75 | 29.55 | 725 | 619 |

*These values are calculated.
†Spacings above 22 cm. are calculated.

The maximum variation from the average between the limits may be 2 per cent. When $x$ is less than $0.54\sqrt{R}$, $g_s$ increases very rapidly because the spacing is then less than the "rupturing energy distance."[5] Above $x = 3R$, $g_v$ apparently gradually increases[5]. This increase seems only apparent and due to the

4. See *Law of Corona III*, F. W. Peek, Jr., A. I. E. E., June, 1913.
5. Ibid.

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shanks, surrounding objects, etc., better distributing the flux or lessening the flux density. When both spheres are insulated and of practical size, the change is not great within the prescribed limits. When one sphere is grounded, however, this apparent increase of gradient is very great if the mathematical $f$, which does not take account of the effect of surrounding objects, is used. For this reason this $f$ was found experimentially, assuming $g_s$ constant within the limits as it is in the non-grounded case,

TABLE V

SPHERE-GAP SPARK-OVER VOLTAGES.
100-cm. DIAMETER SPHERE.

| Spacing | | Kilovolts effective | |
|---|---|---|---|
| cm. | in. | Non-grounded | Grounded |
| 1.0 | 0.394 | 20 | 20 |
| 3.0 | 1.181 | 60 | 60 |
| 5.0 | 1.969 | 100 | 100 |
| 10.0 | 3.937 | 195 | 195 |
| 15.0 | 5.91 | 283. | 280 |
| 20.0 | 7.87 | 364 | 360 |
| 30.0 | 11.81 | 520. | 505 |
| 40.0 | 15.75 | 650 | 615. |
| 50.0 | 19.69 | 770 | 730 |
| 60.0 | 23.62 | 870 | 810 |
| 70.0 | 27.56 | 956 | 895 |
| 80.0 | 31.50 | 1044. | 956 |
| 90.0 | 35.43 | 1107 | 1010 |
| 100.0 | 39.37 | 1182 | 1057 |
| 110.0 | 43.35 | 1238 | 1090 |
| 120.0 | 47.20 | 1290 | 1133 |
| 130.0 | 51.20 | 1335 | 1160 |
| 140.0 | 55.70 | 1378 | 1189 |
| 150.0 | 59.10 | 1412 | 1212 |

These values are calculated.

and finding values of $f_0$ corresponding to the different values of $\frac{x}{R}$. Any given value of the ratio $\frac{x}{R}$ should require a constant $f_0$ to keep $g_s$ constant independent of $R$. This was found to check.

The curves may be very approximately calculated thus:

$$e_s = g_s \frac{x}{f} \text{ (non-grounded) effective sine wave.} \qquad (2)$$

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$$e_s = g_s \frac{x}{f_o} \quad \text{(grounded) effective sine wave} \qquad (3)$$

where $g_s$ is calculated from equation (**1b**), and $f_0$ or $f$ are found from the table for the given $\frac{x}{R}$. These equations have been given for theoretical rather than practical reasons. *Curves*

TABLE VI

SPHERE-GAP GRADIENT FACTOR.

| $\frac{X}{R}$ | Non-grounded mathematical and actual practical coefficient* $f$ | One sphere grounded. Actual practical coefficient $f_0$ | One sphere grounded. Mathematical coefficient not correct on account of effect of shanks, etc.† $f_1$ |
|---|---|---|---|
| 0.1 | 1.034 | 1.035 | 1.050 |
| 0.3 | 1.103 | 1.105 | 1.162 |
| 0.5 | 1.175 | 1.18 | 1.28 |
| 1.0 | 1.366 | 1.41 | 1.62 |
| 1.5 | 1.568 | 1.675 | 2.00 |
| 2.0 | 1.781 | 1.965 | 2.415 |
| 2.5 | 2.002 | 2.27 | 2.85 |
| 3.0 | 2.225 | 2.59 | 3.30 |
| 3.5 | 2.455 | 2.90 | 3.76 |
| 4.0 | 2.686 | 3.20 | 4.23 |

*Non-grounded—$f = \frac{1}{4}\left(\frac{X}{R} + 1 + \sqrt{\left(\frac{X}{R} + 1\right)^2 + 8}\right)$

$f_0$ = experimental values.

†One sphere grounded

$$f_1 = \frac{1}{2}\left(\frac{X}{R} + \sqrt{\left(\frac{X}{R}\right)^2 + 4}\right)$$

$f_1$ should not be used—see note above.

*should be calculated only when standard measured curves cannot be obtained.* Measured curves are given here. The average error, however, for curves calculated from the above equations, for 2-cm. diameter spheres and over, should not be greater than 2 or 3 per cent. The accuracy of calculations is not as great as in the case of the starting point of corona on wires.

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EFFECT OF AIR DENSITY OR ALTITUDE AND TEMPERATURE

We have found that the average gradient for various air densities may be expressed

$$g_s = 27.2\,\delta\left(1 + \frac{0.54}{\sqrt{\delta R}}\right) \text{ kv. per cm. max.}$$

$$g_s = 19.3\,\delta\left(1 + \frac{0.54}{\sqrt{\delta R}}\right) \text{ kv. per cm. effective}$$

where $\delta$ is the relative air density

$$\delta = \frac{3.92\,b}{273+t}$$

$b$ = barometric pressure in cm.
$t$ = temperature in deg. cent.

The standard sea-level curves correspond to 76 cm. barometric pressure and 25 deg. cent. or where $\delta = 1$.

*Correction Factor.* The standard curve may be made to apply to any given altitude by multiplying the voltage at different spacings by the correction factor, thus:

$$e_1 = e\left\{\frac{19.3\,\delta\left(1 + \frac{0.54}{\sqrt{\delta R}}\right)}{19.3\left(1 + \frac{0.54}{\sqrt{R}}\right)}\right\} \tag{4}$$

$$= e\,\delta\,\frac{\left(1 + \frac{0.54}{\sqrt{\delta R}}\right)}{\left(1 + \frac{0.54}{\sqrt{R}}\right)} = e\,k$$

*Practical Application.* In order to avoid the trouble of calculating in practise, the factor is tabulated in Tables VII and VIII. This correction is very accurate. Table VII gives the correction factor for different sizes of spheres at different barometric pressures and at constant temperature. When volt-

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TABLE VII

| Approximate corresponding altitude ft. | Barometer | | Values of $k$ at 25 deg. cent. for standard spheres of the following diameter. Centimeters. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | cm. Hg | in. Hg | 6.25 | 12.5 | 25 | 37.5 | 50 | 75 | 100 |
| 0 | 76.00 | 29.92 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 500 | 74.58 | 29.36 | 0.981 | 0.980 | 0.980 | 0.979 | 0.979 | 0.979 | 0.979 |
| 1,000 | 73.14 | 28.79 | 0.964 | 0.963 | 0.962 | 0.961 | 0.960 | 0.960 | 0.960 |
| 1,500 | 71.77 | 28.25 | 0.948 | 0.946 | 0.945 | 0.944 | 0.943 | 0.942 | 0.942 |
| 2,000 | 70.42 | 27.72 | 0.932 | 0.929 | 0.927 | 0.926 | 0.925 | 0.924 | 0.924 |
| 2,500 | 69.09 | 27.20 | 0.916 | 0.913 | 0.911 | 0.909 | 0.908 | 0.907 | 0.907 |
| 3,000 | 67.74 | 26.67 | 0.902 | 0.899 | 0.897 | 0.895 | 0.893 | 0.892 | 0.891 |
| 3,500 | 66.51 | 26.18 | 0.887 | 0.884 | 0.882 | 0.880 | 0.878 | 0.876 | 0.875 |
| 4,000 | 65.25 | 25.69 | 0.873 | 0.870 | 0.867 | 0.865 | 0.863 | 0.861 | 0.860 |
| 4,500 | 64.01 | 25.23 | 0.859 | 0.855 | 0.852 | 0.850 | 0.848 | 0.846 | 0.845 |
| 5,000 | 62.79 | 24.72 | 0.845 | 0.841 | 0.838 | 0.835 | 0.833 | 0.831 | 0.830 |
| 6,000 | 60.45 | 23.80 | 0.817 | 0.812 | 0.808 | 0.805 | 0.803 | 0.801 | 0.800 |
| 7,000 | 58.22 | 22.93 | 0.791 | 0.786 | 0.782 | 0.779 | 0.776 | 0.774 | 0.772 |
| 8,000 | 56.03 | 22.05 | 0.765 | 0.759 | 0.754 | 0.750 | 0.748 | 0.746 | 0.744 |
| 9,000 | 53.84 | 21.20 | 0.739 | 0.733 | 0.728 | 0.724 | 0.721 | 0.719 | 0.717 |
| 10,000 | 51.85 | 20.41 | 0.716 | 0.709 | 0.703 | 0.698 | 0.694 | 0.692 | 0.690 |
| 12,000 | 48.09 | 18.93 | 0.669 | 0.661 | 0.656 | 0.651 | 0.647 | 0.644 | 0.642 |
| 15,000 | 42.88 | 16.88 | 0.606 | 0.596 | 0.589 | 0.585 | 0.580 | 0.577 | 0.575 |

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age strikes across a given gap, its value, $e_1$, may be found by taking the voltage $e$, corresponding to the gap, from the standard curve and multiplying by the correction factor $k$, or a curve may be plotted corresponding to a given barometric pressure, thus

$$e_1 = ek.$$

TABLE VIII

Calculated values of $k$ for different values of

$$k = \delta \left\{ \frac{1 + \frac{0.54}{\sqrt{\delta R}}}{1 + \frac{0.54}{\sqrt{R}}} \right\}$$

$$= \sqrt{\delta}\, \frac{\sqrt{\delta R} + 0.54}{\sqrt{R} + 0.54}$$

| Relative air density | Values of $k$. Diameter of standard spheres in cm. | | | | | | |
|---|---|---|---|---|---|---|---|
| $\delta$ | 6.25 | 12.5 | 25. | 37.5 | 50. | 75. | 100. |
| 0.50 | 0.547 | 0.535 | 0.527 | 0.522 | 0.519 | 0.519 | 0.516 |
| 0.55 | 0.594 | 0.583 | 0.575 | 0.570 | 0.567 | 0.565 | 0.564 |
| 0.60 | 0.640 | 0.630 | 0.623 | 0.618 | 0.615 | 0.613 | 0.612 |
| 0.65 | 0.686 | 0.677 | 0.670 | 0.665 | 0.663 | 0.661 | 0.660 |
| 0.70 | 0.732 | 0.724 | 0.718 | 0.714 | 0.711 | 0.709 | 0.708 |
| 0.75 | 0.777 | 0.771 | 0.766 | 0.762 | 0.759 | 0.757 | 0.756 |
| 0.80 | 0.821 | 0.816 | 0.812 | 0.809 | 0.807 | 0.805 | 0.804 |
| 0.85 | 0.866 | 0.862 | 0.859 | 0.857 | 0.855 | 0.854 | 0.853 |
| 0.90 | 0.910 | 0.908 | 0.906 | 0.905 | 0.904 | 0.903 | 0.902 |
| 0.95 | .956 | .955 | .954 | .953 | .952 | .951 | .951 |
| 1.00 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 1.05 | 1.044 | 1.045 | 1.046 | 1.047 | 1.048 | 1.049 | 1.049 |
| 1.10 | 1.090 | 1.092 | 1.094 | 1.095 | 1.096 | 1.097 | 1.098 |

Table VIII gives the correction factor for various values of $\delta$. The value of $\delta$ may be calculated for the given temperature and barometric pressure and a correction factor then found from the table. Fig. 3 gives the standard curve for the 12.5-cm. sphere (non-grounded, 25 deg. cent., 76 cm. bar. pressure) and curves calculated therefrom for 25 deg. cent. and various barometric pressures.

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EXPERIMENTAL DETERMINATION OF AIR DENSITY CORRECTION

*Tests.* The equation (**4**) for the air density correction factor was determined by an extensive investigation of the spark-over of spheres in a large wooden cask arranged for exhaustion of air. This cask was built of paraffined wood and was 2.1 meters high by 1.8 meters inside diameter.

Tests were made by setting a given size of sphere at a given spacing, gradually exhausting the cask, and reading spark-over voltage at intervals as the air pressure was changed. (Temperature was always read, but varied only between 16 deg. and 21 deg. cent). This was repeated for various spacings on spheres ranging in diameter from 2.0 cm. to 25 cm. At the start, the

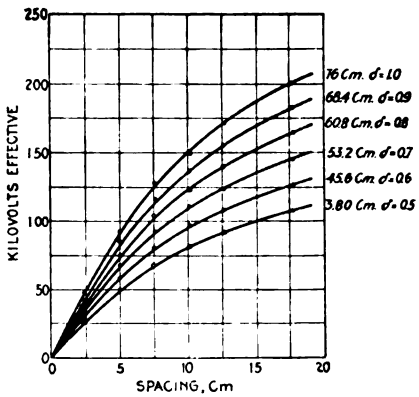


FIG. 3—SPHERE GAP SPARK-OVER VOLTAGE AT VARIOUS AIR PRESSURES

Temperature 25 deg.cent. 12.5-cm. spheres. Non-grounded. Drawn curves calculated. 76 cm. is standard curve. Points are from curves through measured values.

possible effect of spark-overs on the succeeding ones in the cask was investigated and found to be nil or negligible. A resistance of one to four ohms per volt was used in series with the spheres. Wave shape was measured and corrected for. Voltage was read on a voltmeter coil, by step-down transformer, and by ratio. Precautions were taken as noted in the discussion referred to below.[6]

In order to illustrate the method of recording data, etc., a small part of the data for various spheres and spacings is given in Tables IX to XVIII. Numerous data are plotted in curves,

6. *The Calibration of the Sphere-Gap Voltmeter*, A.I.E.E., Feb., 1913 Discussion by F. W. Peek, Jr.

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TABLE IX

SPHERE-GAP SPARK-OVER VOLTAGE AND GRADIENTS

2.54-cm. DIAMETER SPHERES—NON-GROUNDED.

| Spacing cm. | Spacing in. | Temp deg. cent. | Press. in. of Hg | Relative air density | kv eff. | kv max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|---|---|
| 0.635 | 0.25 | 15 | 29.78 | 1.028 | 15.7 | 22.2 | 29.2 | 41.3 |
| | | | 28.63 | 0.99 | 15.3 | 21.65 | 28.5 | 40.3 |
| | | | 27.73 | 0.957 | 14.9 | 21.1 | 27.7 | 39.2 |
| | | | 26.93 | 0.93 | 14.4 | 20.4 | 26.8 | 23.0 |
| | | | 25.93 | 0.895 | 14.0 | 19.8 | 26.0 | 36.8 |
| | | | 24.68 | 0.852 | 13.6 | 19.2 | 25.3 | 35.7 |
| | | | 23.63 | 0.818 | 13.2 | 18.7 | 24.6 | 34.8 |
| | | | 22.38 | 0.776 | 12.5 | 17.2 | 23.25 | 32.0 |
| | | | 21.58 | 0.745 | 12.1 | 17.1 | 22.5 | 31.8 |
| | | | 20.78 | 0.717 | 11.8 | 16.7 | 22.0 | 31.1 |
| | | | 19.88 | 0.686 | 11.3 | 16.0 | 21.0 | 29.8 |
| | | | 18.78 | 0.649 | 10.75 | 15.2 | 20.0 | 28.3 |
| | | | 17.88 | 0.618 | 10.4 | 14.7 | 19.35 | 27.4 |
| | | | 16.68 | 0.576 | 9.8 | 13.85 | 18.25 | 25.8 |
| | | | 15.73 | 0.544 | 9.26 | 13.1 | 17.2 | 24.4 |
| | | | 14.48 | 0.500 | 8.66 | 12.25 | 16.1 | 22.8 |

Barometer 29.78 in.

TABLE X

SPHERE-GAP SPARK-OVER VOLTAGE AND GRADIENTS

2.54-cm. DIAMETER SPHERES—NON-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv eff. | kv max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 3.81 | 1.5 | 1.01 | 52.4 | 74.2 | 29.2 | 41.4 |
| " | " | 0.962 | 50.5 | 71.5 | 28.1 | 39.8 |
| " | " | 0.923 | 49.1 | 69.5 | 27.4 | 38.7 |
| " | " | 0.875 | 45.7 | 64.6 | 25.5 | 36.0 |
| " | " | 0.834 | 45.2 | 64.0 | 25.2 | 35.7 |
| " | " | 0.798 | 42.8 | 60.6 | 23.8 | 33.8 |
| " | " | 0.757 | 41.3 | 58.5 | 23.0 | 32.6 |
| " | " | 0.734 | 40.4 | 57.2 | 22.5 | 31.9 |
| " | " | 0.722 | 39.0 | 55.1 | 21.7 | 30.7 |
| " | " | 0.669 | 38.0 | 53.8 | 21.2 | 30.0 |
| " | " | 0.629 | 35.6 | 50.4 | 19.8 | 28.1 |
| " | " | 0.590 | 34.1 | 48.3 | 19.0 | 26.9 |
| " | " | 0.551 | 32.7 | 46.3 | 18.2 | 25.8 |
| " | " | 0.527 | 31.2 | 44.3 | 17.4 | 24.7 |
| " | " | 0.487 | 30.5 | 43.2 | 17.0 | 24.1 |

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TABLE XI

SPHERE-GAP SPARK-OVER VOLTAGE AND GRADIENT

5.08-cm. DIAMETER SPHERES—NON-GROUNDED

| Spacing cm. | Spacing in. | Relative air density | kv. eff. | kv. max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 5.08 | 2 | 1.018 | 78.4 | 111.0 | 27.4 | 38.9 |
| " | " | 0.98 | 75.6 | 107. | 26.5 | 37.6 |
| " | " | 0.944 | 73.1 | 103.5 | 25.6 | 36.2 |
| " | " | 0.903 | 7.07 | 100. | 24.8 | 35.0 |
| " | " | 0.872 | 68.7 | 97.2 | 24.0 | 34.0 |
| " | " | 0.836 | 64. | 90.5 | 22.4 | 31.7 |
| " | " | 0.798 | 63.6 | 90. | 22.3 | 31.5 |
| " | " | 0.764 | 61.1 | 86.4 | 21.4 | 30.2 |
| " | " | 0.726 | 58.9 | 83.3 | 20.6 | 29.2 |
| " | " | 0.682 | 56.1 | 80.5 | 19.6 | 28.2 |
| " | " | 0.654 | 54.0 | 76.4 | 18.9 | 26.8 |
| " | " | 0.618 | 51.5 | 73.0 | 18.0 | 25.6 |
| " | " | 0.578 | 49.0 | 69.3 | 17.2 | 24.3 |
| " | " | 0.544 | 45.8 | 64.7 | 16.0 | 22.6 |
| " | " | 0.510 | 43.3 | 61.2 | 15.2 | 21.4 |

TABLE XII

SPHERE-GAP SPARK-OVER VOLTAGES AND GRADIENTS

12.5-cm. DIAMETER SPHERES—NON-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv. eff. | kv. max. | $g_s$ eff. measured. | $g_s$ max. measured. |
|---|---|---|---|---|---|---|
| 2.54 | 1 | 1.016 | 52.4 | 74.1 | 23.6 | 33.4 |
| " | " | 0.966 | 49.9 | 67.9 | 22.4 | 30.6 |
| " | " | 0 928 | 47.4 | 67.0 | 21.3 | 30.2 |
| " | " | 0.88 | 45.4 | 64.2 | 20.4 | 28.9 |
| " | " | 0.83 | 42.5 | 60.1 | 19.2 | 27.1 |
| " | " | 0.778 | 40.0 | 56.6 | 18.0 | 25.5 |
| " | " | 0.738 | 38.4 | 54.3 | 17.3 | 24.4 |
| " | " | 0.705 | 36.0 | 52.2 | 16.6 | 23.5 |
| " | " | 0.644 | 33.4 | 47.2 | 15.0 | 21.2 |
| " | " | 0.607 | 31.4 | 44.5 | 14.1 | 20.0 |
| " | " | 0.558 | 29.4 | 41.6 | 13.2 | 18.7 |
| " | " | 0.538 | 29.6 | 41.8 | 13.3 | 18.8 |
| " | " | 0.493 | 27.4 | 38.8 | 12.3 | 17.5 |

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TABLE XIII

SPHERE-GAP SPARK-OVER AND GRADIENT.

12.5-cm. DIAMETER SPHERES—NON-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv. eff. | kv. max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 5.08 | 2 | 1.02 | 91. | 129. | 23. | 33.65 |
| | | 0.962 | 87.4 | 123.5 | 22.1 | 31.25 |
| | | 0.925 | 84.6 | 120. | 21.4 | 30.40 |
| | | 0.89 | 81.9 | 115.8 | 20.7 | 29.25 |
| | | 0.846 | 78.1 | 110.5 | 18.73 | 27.95 |
| | | 0.81 | 76.3 | 107.9 | 19.26 | 27.25 |
| | | 0.754 | 71.6 | 100. | 18.1 | 25.30 |
| | | 0.707 | 66. | 93.5 | 16.7 | 23.65 |
| | | 0.661 | 64.1 | 90.6 | 16.2 | 22.90 |
| | | 0.603 | 59.3 | 84. | 15.0 | 21.25 |
| | | 0.559 | 53.9 | 76.1 | 13.64 | 19.25 |
| | | 0.532 | 52.0 | 73.5 | 13.15 | 18.60 |
| | | 0.506 | 50.1 | 71. | 12.65 | 17.95 |

TABLE XIV

SPHERE-GAP SPARK-OVER VOLTAGE AND GRADIENT.

12.5-cm. DIAMETER SPHERES—NON-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv. eff. | kv. max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 10.16 | 4 | 1.004 | 145.0 | 205.0 | 23.0 | 32.55 |
| " | " | 0.965 | 144. | 203.7 | 22.85 | 32.30 |
| " | " | 0.93 | 139 | 196.6 | 22.10 | 31.20 |
| " | " | 0.90 | 137. | 194. | 21.78 | 30.80 |
| " | " | 0.865 | 131.8 | 186.5 | 20.95 | 29.65 |
| " | " | 0.859 | 131.5 | 186.2 | 20.85 | 29.60 |
| " | " | 0.793 | 123.7 | 175.0 | 19.60 | 27.80 |
| " | " | 0.762 | 120.8 | 171.0 | 19.20 | 27.20 |
| " | " | 0.739 | 115.7 | 163.6 | 18.36 | 26.00 |
| " | " | 0.685 | 110.2 | 156.0 | 17.50 | 24.80 |
| " | " | 0.67 | 105.9 | 149.7 | 16.80 | 23.75 |
| " | " | 0.623 | 100. | 141.4 | 15.90 | 22.45 |
| " | " | 0.595 | 96.6 | 136.6 | 15.34 | 21.70 |
| " | " | 0.534 | 88.3 | 125.0 | 14.05 | 19.85 |
| " | " | 0.503 | 82.2 | 116.4 | 13.05 | 18.50 |

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TABLE XV

SPHERE-GAP SPARK-OVER VOLTAGES AND GRADIENT.

12.5-cm. DIAMETER SPHERE—NON-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv. eff. | kv. max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 12.7 | 5 | 0.982 | 163.0 | 230.0 | 23.1 | 32.7 |
| " | " | 0.951 | 156. | 221.0 | 22.2 | 31.4 |
| " | " | 0.917 | 150 | 212.5 | 21.3 | 30.2 |
| " | " | 0.88 | 147 | 208 | 20.9 | 29.5 |
| " | " | 0.846 | 143.5 | 203 | 20.4 | 29.8 |
| " | " | 0.807 | 139.5 | 197.5 | 19.8 | 28.0 |
| " | " | 0.78 | 134.5 | 190 | 19.1 | 27.0 |
| " | " | 0.736 | 131 | 185.5 | 18.6 | 26.3 |
| " | " | 0.699 | 125 | 177 | 17.7 | 25.1 |
| " | " | 0.666 | 120.5 | 170 | 17.1 | 24.2 |
| " | " | 0.637 | 115.5 | 163 | 16.4 | 23.1 |
| " | " | 0.598 | 109.5 | 155 | 15.5 | 22.0 |
| " | " | 0.561 | 104.5 | 147.5 | 14.8 | 21.0 |
| " | " | 0.541 | 101 | 142.5 | 14.3 | 20.2 |

TABLE XVI

SPHERE-GAP SPARK-OVER VOLTAGE AND GRADIENT

12.5-cm. DIAMETER SPHERES—NON-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv. eff. | kv. max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 20.32 | 8 | 0.938 | 198.5 | 281 | 23.0 | 32.6 |
| " | " | 0.912 | 197 | 279 | 22.9 | 32.4 |
| " | " | 0.874 | 189.5 | 268 | 22.0 | 31.1 |
| " | " | | | | | |
| " | " | 0.842 | 183 | 259 | 21.2 | 28.9 |
| " | " | 0.804 | 176.5 | 250 | 20.5 | 29.0 |
| " | " | 0.767 | 169 | 239 | 19.6 | 27.8 |
| " | " | | | | | |
| " | " | 0.737 | 163.5 | 231 | 19.0 | 26.8 |
| " | " | 0.704 | 157.5 | 223 | 18.3 | 24.7 |
| " | " | 0.674 | 151 | 235 | 17.5 | 24.8 |
| " | " | | | | | |
| " | " | 0.615 | 140.0 | 198.0 | 16.2 | 23.0 |
| " | " | 0.568 | 130.5 | 184.5 | 15.1 | 21.4 |
| " | " | 0.528 | 120.5 | 171 | 14.0 | 19.8 |
| " | " | | | | | |
| " | " | 0.488 | 110 | 157 | 12.8 | 18.2 |
| | | 0.464 | 105.5 | 149 | 12.2 | 17.3 |

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TABLE XVII

SPHERE-GAP SPARK-OVER AND GRADIENT

12.5-cm. DIAMETER SPHERE-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv eff. | kv max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 6.35 | 2.5 | 0.908 | 95.5 | 135 | 21.2 | 30.0 |
| | | 0.869 | 92.5 | 130.5 | 20.5 | 29.0 |
| | | 0.828 | 88.6 | 125 | 19.7 | 27.8 |
| | | 0.796 | 85.8 | 121 | 19.05 | 26.9 |
| | | 0.758 | 81.1 | 114.5 | 18.0 | 25.4 |
| | | 0.723 | 78.2 | 110.5 | 17.35 | 24.5 |
| | | 0.69 | 73.2 | 103.5 | 16.25 | 23.0 |
| | | 0.653 | 71.5 | 101 | 15.9 | 22.4 |
| | | 0.62 | 68.2 | 96.3 | 15.15 | 21.4 |
| | | 0.582 | 64.3 | 90.9 | 14.25 | 20.2 |
| | | 0.539 | 60.7 | 85.8 | 13.5 | 19.05 |
| | | 0.439 | 55.6 | 78.5 | 12.35 | 17.4 |

TABLE XVIII

SPHERE-GAP SPARK-OVER VOLTAGE AND GRADIENT.

25-cm. DIAMETER SPHERE—NON-GROUNDED.

| Spacing cm. | Spacing in. | Relative air density | kv eff. | kv max. | $g_s$ eff. measured | $g_s$ max. measured |
|---|---|---|---|---|---|---|
| 7.62 | 3 | 1.018 | 139 | 196.5 | 22.2 | 31.5 |
| | | 0.978 | 133.5 | 189 | 21.4 | 30.3 |
| | | 0.942 | 129.5 | 183 | 20.8 | 29.3 |
| | | 0.906 | 126 | 178 | 20.2 | 28.5 |
| | | 0.888 | 121.5 | 172 | 19.5 | 27.6 |
| | | 0.839 | 115 | 163 | 18.4 | 26.1 |
| | | 0.796 | 111 | 157 | 17.8 | 25.2 |
| | | 0.752 | 105.5 | 149 | 16.9 | 23.9 |
| | | 0.718 | 101.5 | 142 | 16.3 | 22.7 |
| | | 0.685 | 96.2 | 136 | 15.4 | 21.8 |
| | | 0.646 | 91.5 | 129.5 | 14.6 | 20.7 |
| | | 0.608 | 87.0 | 123 | 13.9 | 19.7 |
| | | 0.570 | 81.3 | 115 | 13.0 | 18.4 |
| | | 0.527 | 74.7 | 105.5 | 12.0 | 16.9 |
| | | 0.491 | 70.8 | 100 | 11.3 | 16.0 |

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Figs. 4 to 8. The points are measured values. The drawn lines are calculated by multiplying the voltage values from the standard curves at $\delta = 1$, by the correction factor $k$.

$$k = \delta \frac{\left(1 + \frac{0.54}{\sqrt{\delta R}}\right)}{\left(1 \quad \frac{0.54}{\sqrt{R}}\right)}$$

The calculated values check the measured values very closely.

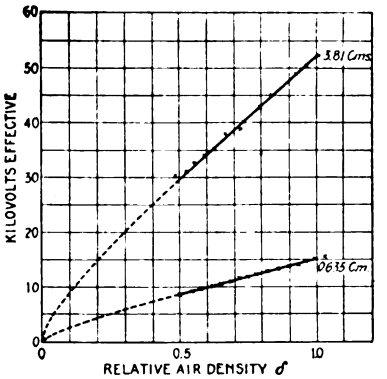


FIG. 4—SPARK-OVER VOLTAGE WITH VARYING AIR DENSITIES

2.54-cm. (1-in.) spheres. Non-grounded. Spacing 3.81 cm. (1.5 in.), 0.635 cm. (0.25 in.)

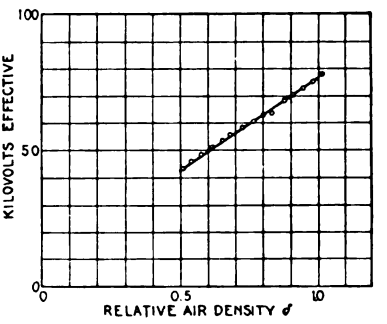


FIG. 5—SPARK-OVER VOLTAGE WITH VARYING AIR DENSITIES

5.08-cm. (2-in.) spheres. Non-grounded. Spacing 5.08 cm. (2 in.).

The equation for the correction factor was deduced from measured values as follows:

From a former investigation[7] it was found that at $\delta = 1$ the average gradient

$$g_s = g_0\left(1 + \frac{0.54}{\sqrt{R}}\right) \qquad (1)$$

From the present investigation it was found that the average gradient at various values of $\delta$ is

$$g_s = g_0\,\delta\left(1 + \frac{0.54}{\sqrt{\delta R}}\right)$$

7. *Law of Corona III.* F. W. Peek, Jr., A.I.E.E., June 1913. Discussion, Feb. 1913.

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The average measured gradients for various values of $\delta$ are given in Table XIX; values calculated from the equation are also given. The check is quite close. It should be remembered, however, that these are average values and that there is a small varia-

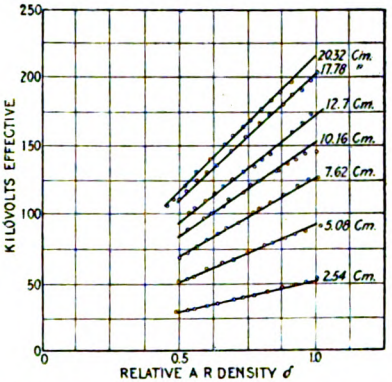


FIG. 6—SPARK-OVER VOLTAGE WITH VARYING AIR DENSITIES
12.5-cm. (4 15/16 in.) spheres. Non-grounded.

Spacing { 2.54 cm. (1 in.); 5.08 cm. (2 in.); 7.62 cm. (3 in.); 10.16 cm. (4 in.); 12.7 cm. (5 in.); 17.78 cm. (7 in.); 20.32 cm. (8 in.) }

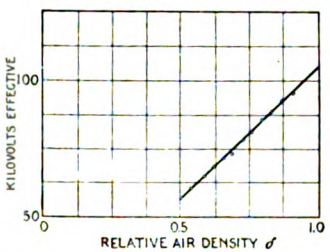


FIG. 7—SPARK-OVER VOLTAGE WITH VARYING AIR DENSITIES
12.5-cm. (4 15/16-in.) spheres grounded.
Spacing 6.35 cm. (2.5 in.).

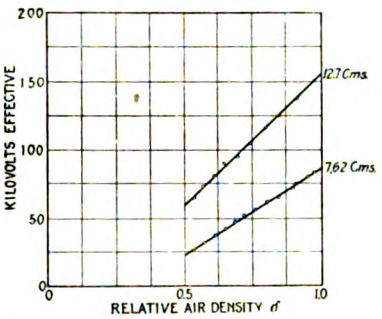


FIG. 8—SPARK-OVER VOLTAGE WITH VARYING AIR DENSITIES
25-cm. (9 7/8-in.) spheres, non-grounded.
Spacing { 12.7 cm. (5 in.). 7.62 cm. (3 in.). }

tion at different spacings over this range, as already explained. (See Figs. 9 and 10).

## FREQUENCY

Over the commercial range there is no variation due to frequency. Fig. 11 shows spark-over curves up to 25 kv.

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TABLE XIX

AVERAGE EFFECTIVE RUPTURING-GRADIENTS FOR SPHERES OF SEVERAL DIAMETERS AND VARYING AIR DENSITIES.

| $\delta$ | Diameter of Spheres, cm. | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2.54 | | 5.08 | | 12.5 | | 25 | |
| | Surface gradients | | | | | | | |
| | Meas. | Calc. | Meas. | Calc. | Meas. | Calc. | Meas. | Calc. |
| 1.00 | 28.7 | 28.5 | 25.8 | 25.8 | 23.6 | 23.4 | 22.0 | 22.2 |
| 0.90 | 26.2 | 26.1 | 23.7 | 23.3 | 21.8 | 21.2 | 19.9 | 20.1 |
| 0.80 | 24.0 | 23.7 | 21.3 | 21.3 | 19.6 | 19.1 | 17.9 | 18.0 |
| 0.70 | 21.3 | 21.2 | 19.0 | 19.0 | 17.4 | 16.9 | 15.7 | 15.9 |
| 0.60 | 18.7 | 18.7 | 16.7 | 16.6 | 15.2 | 14.7 | 13.6 | 13.8 |
| 0.05 | 16.1 | 16.1 | 14.6 | 14.3 | 13.0 | 12.5 | 11.6 | 11.7 |

Columns marked " Calc. " are from $g_s = 19.3\,\delta\left(1 + \frac{0.54}{\sqrt{\delta R}}\right)$

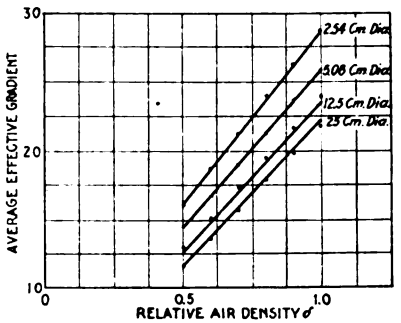


FIG. 9—SURFACE GRADIENT AT VARYING AIR DENSITIES FOR SEVERAL SIZES OF SPHERES

Drawn curves calculated. Points measured values.

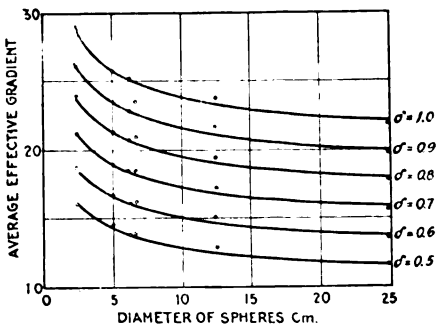


FIG. 10—SURFACE GRADIENT FOR VARYING SIZES OF SPHERES AT SEVERAL AIR DENSITIES.

Drawn lines calculated from formula $g_s = 19.3\delta\left(1 + \frac{0.54}{\sqrt{\delta R}}\right)$

Points measured values.

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with 1000-cycle sine-wave current from an alternator. The voltage was measured by a static voltmeter calibrated at 60 cycles. The drawn curve is the 60-cycle curve and the points are measured values. Fig. 12 gives a 60-cycle curve, and also a 40,000-cycle curve from a sine-wave alternator.

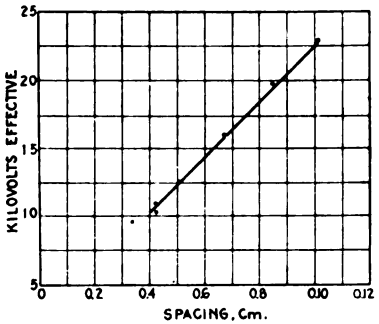


FIG. 11A—SPHERE GAP SPARK-OVER VOLTAGE AT 60 CYCLES AND 1000 CYCLES

5.08-cm. diam. spheres. Drawn curve 60 cycles Points taken at 1000 cycles.

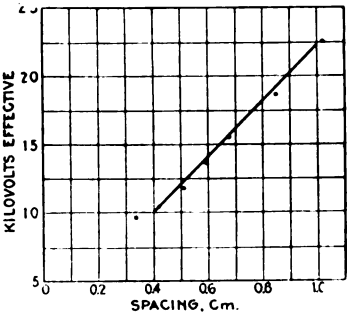


FIG. 11B—SPHERE GAP SPARK-OVER VOLTAGE AT 60 CYCLES AND 1000 CYCLES

12.5-cm. diam. spheres. Drawn curve 60 cycles—points taken at 1000 cycles.

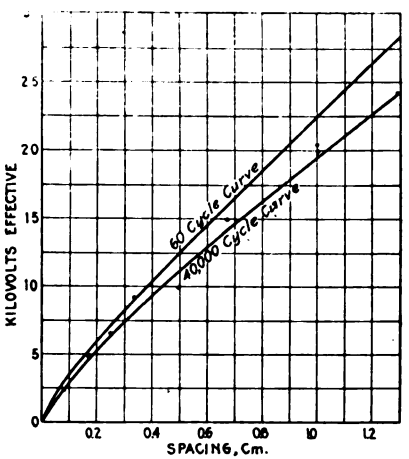


FIG. 12—SPHERE GAP SPARK-OVER VOLTAGE AT 60 CYCLES AND 40,000 CYCLES

Points measured at 40,000 cycles. 5.08-cm. (2-in.) spheres, not polished.

The voltage in this case was measured by a static voltmeter. No special care was taken to polish the sphere surfaces. At low frequencies, at rough places on the electrode surface, there is local-over stress, but even if the air is broken down, the loss at these places is very small and the streamers inappreciable.

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At continuous high frequency, say 40,000 cycles, a local breakdown at a rough point probably takes place at the same gradient as at 60 cycles, but the energy loss after the breakdown at this point occurs may be 1000 times as great. This forms a needle-like streamer which increases the stress and local loss. Spark-over then takes place from this "electric needle" at a lower voltage than the true sphere gap voltage; thus it seems that the air at high frequency of the above order is only apparently of less strength. These "electric needles" when once formed may be blown to different parts of the sphere surface. The corona starting point appears to take place at a lower voltage at high frequency, because the local loss at rough points, which occurs before the true critical voltage is reached is very high at high frequency and distorts the field and masks the true starting voltage. The loss at rough points starts at the same voltage at low frequency, but is inappreciable and cannot change conditions. If the sphere surfaces are very highly polished it seems that the high frequency spark-over voltage should check more closely with the 60-cycle voltage for frequencies of the above order. It also seems that the curves should check very closely for oscillating voltage of short duration and voltages of moderate wave front, even under ordinary conditions of surface. With needle gaps the results are quite different at high and low frequency. More complete investigations are being made.

Care should be taken in attempting to check voltages across one gap of any sort by another gap in parallel. For instance, if a needle gap is set so as to just spark over when a steep wave front voltage of a given constant value is applied, and a sphere gap is similarly set, and these two gaps are then placed in parallel and the same impulse voltage applied, apparent discrepancy results. Spark-over will take place across one gap and not the other, even when the spacing on the non-sparking gap is decreased. This will be noticed in all cases where electrodes of different shapes are employed. The reason, apparently, is that energy is necessary to start rupture in the dielectric, the amount of energy varying with the shape of the electrode. This introduces a time element which differs for different gaps. Thus, in this case the "fastest" gap will spark over and relieve the voltage before the other has time to spark, even if the other gap is decreased.

It is now often said that "high frequency acts differently, on insulation, from low frequency". When the time of applica-

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tion is sufficiently short, say a few cycles, so that the effect of heating may be neglected, and the circuit is such that local concentration of potential is not possible, it is probable that a given high-frequency potential is less destructive than the same low-frequency potential. For steep wave fronts a higher voltage is required to spark over a given gap than for low frequency. Destruction of insulation by high frequency is generally due to local over-voltage, and not to "frequency". For instance, high-frequency low voltage may be applied to a piece of apparatus containing induction and capacity, such as a transformer. On account of the capacity and inductance, very high local over-voltage may be built up and breakdown results due to over-voltage. The petticoats of an insulator may be broken down by an "electric needle", forming as described above, and bringing the total stress on the thin petticoat.

Spectacular tests are sometimes made by placing an insulator in multiple with a gap over which an oscillatory discharge is taking place, such as a Tesla coil gap. This gap is set at a spacing that would limit the voltage to a safe voltage at 60 cycles, yet the insulator is punctured on the oscillatory discharge. This is not remarkable. By the circuit arrangement *many* times the insulator puncture voltage is applied to the gap. This voltage is across the insulator for short intervals just before the gap discharges take place. It is simply a case of over-potential.

Such tests are useful in many cases, but are dangerous to apparatus unless thoroughly understood and necessary precaution taken.

### Precautions against Oscillations in Testing

A non-inductive resistance of one to four ohms per volt should always be placed directly in series with the gap. For the non-grounded gap, one-half should be placed on each side. When one gap is grounded all of the resistance should be placed on the insulated side. One object of the resistance is to prevent oscillations from the test piece, as a partial arc-over on a line insulator, reaching the gap. Accuracy cannot be secured without this resistance. Another object is to limit the current discharge. This resistance is of special importance when tests are being made on apparatus containing inductance and capacity. If there is no resistance, when the gap sparks over oscillations will be produced which will cause very high

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local voltage rise over parts of the winding. If sufficient resistance is used, these oscillations will be damped out. This is illustrated in Fig. 13, which shows results of a test on a high-voltage transformer on which a 19-cm. gap test is required.

Referring to Fig. 13, the high-voltage winding of the transformer under test is short-circuited and connected to one terminal of the testing transformer. The other terminal of the testing transformer is grounded. The low-voltage winding of the transformer under test is short-circuited, connected to the case and ground. Voltage is gradually applied to the trans-

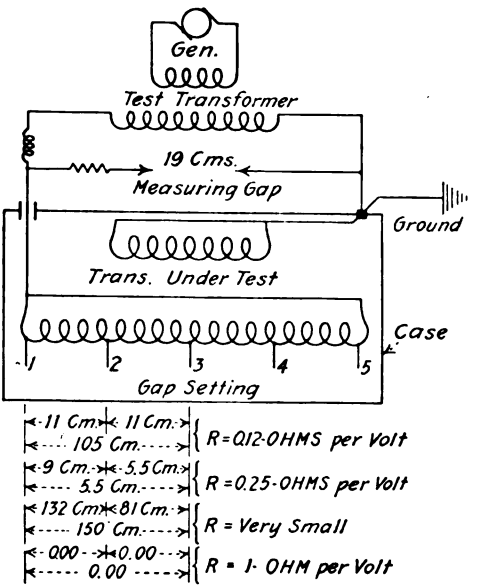


FIG. 13

former under test until the "measuring gap" sparks over. Insulated taps, 1, 2, 3, 4, 5, are brought out at equidistant points from the high-tension winding of the transformer under test. Auxiliary needle gaps are placed between 1 and 2, 2 and 3 and 1 and 3, to measure the voltage which appears across these sections of the winding when the main measuring gap discharges. The numbers on the figure between 1–2, 2–3 and 1–3, represent the sparking distances of the local voltages caused by a discharge of the measuring gap. Four cases are given with different values of resistance ($R$) in the main gap. When

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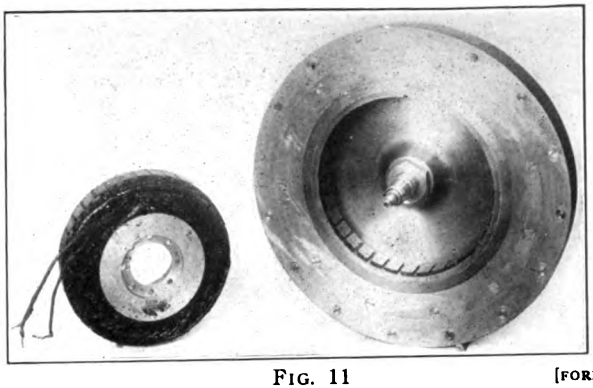

FIG. 11 [FORD]

Rotor and Stator of the Gyro Motor.

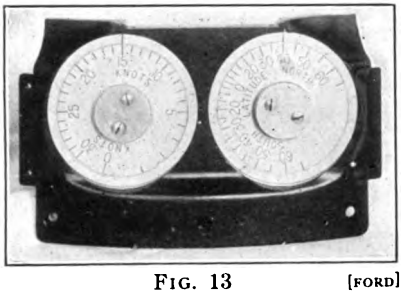

FIG. 13 [FORD]

Automatic Correction Dials. Setting 15 knots, 40 deg. North Latitude.

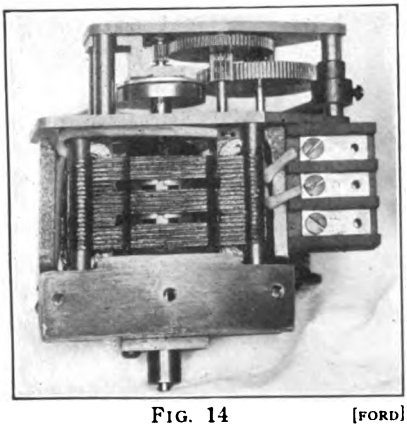

FIG. 14 [FORD]

Azimuth Motor for Driving the Phantom.

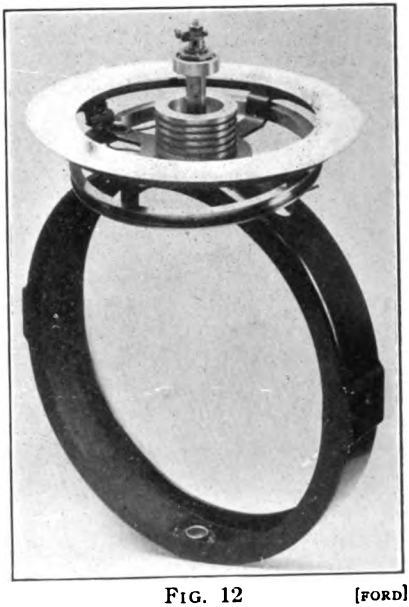

FIG. 12 [FORD]

Power-Driven Frame or "Phantom" arranged to Shield the Directive Element from External Disturbances.

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$R$ equals one ohm per volt the local voltages are completely damped out.

With small resistance in the main gap, a 19-cm. spark-over causes a voltage to build up between coils one and three which sparks over a 150-cm. gap, although the total applied voltage across the transformer is only equivalent to 19-cm. gap. The apparatus may thus be subjected to strains far beyond reason, and either broken down or very much weakened. Water-tube resistance is the most reliable. A metallic resistance, if non-inductive and of small capacity, may be used. Carbon or graphite rods should be avoided, because, although they may measure up to a very high resistance at low voltage, the resistance may become very low at high voltage by "coherer" action. Where possible the gap should be used only to measure the equivalent transformer ratio and not during test.

TABLE XX

POSSIBLE ERROR DUE TO PLATES ON SPHERE SHANKS.

(IN PER CENT)

| cm. | Non-grounded 1.5 R. cm. Diameter Plates. 1/4 R. cm. Back of | | Grounded 1.5 R. Grounded Plates. 1/4 R. cm. Back of | |
|---|---|---|---|---|
| | Both spheres | One sphere only | Insulated sphere | Grounded sphere |
| 0.5 R | 0.00 | 0.00 | | 0.00 |
| 2 R | +0.05 | 1.50 | +3.00 | 0.00 |
| R | +3.00 | 7.00 | +6 to 10 | 0.00 |

Spacings are in terms of radius R.

The error is not appreciable when the collars are at the maximum gap spacing behind spheres and not greater than R. cm. in diameter. This table is not meant for use in making corrections. The stand should be arranged so that no corrections are necessary.

## MISCELLANEOUS PRECAUTIONS

In making tests it is desirable to observe the following precautions:

The shanks should not be greater in diameter than 1/5 the sphere diameter. Metal collars, etc., through which shanks extend, should be as small as practicable, and should not come closer to the sphere than the gap length. For the non-grounded case the effect of such objects is a minimum when symmetrical on

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either side. For the grounded case the effect is considerable, except when the object is on the grounded side. The effect of a large plate or plates on the shanks is given in Table XX. This should show the maximum error in all cases, as the maximum gap setting, and the extreme diameter of collar that is likely to be used in practise, is taken. The sphere diameter should not vary more than 0.1 per cent, and the curvature, measured by a spherometer, should not vary more than 1 per cent from that of a true sphere of the required diameter. The spheres should be twice the gap setting from surroundings.

The author wishes to acknowledge the assistance of Mr. H. K. Humphrey in laboratory work and in making calculations.

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(*Subject to final revision for the Transactions.*)

# THE ELECTRIC STRENGTH OF AIR—V
## The Influence of Frequency

BY J. B. WHITEHEAD AND W. S. GORTON

ABSTRACT OF PAPER

The paper presents the account of an investigation of the influence of frequency on the corona, between 60 and 3000 cycles per second. The wire and coaxial cylinder method was used.

A simple method for measuring the maximum value of an alternating voltage wave has been developed and used for obtaining this maximum value at the critical corona voltage. The gold-leaf electroscope was used to detect the first appearance of corona.

It has been found that for frequencies above 275 cycles per second the corona voltage (maximum value) is not so uniform and constant as it is at frequencies in the neighborhood of 60 cycles.

The indications of the investigation are that at 2000 cycles the corona voltage is lower than it is at 60 cycles by about 3 or 4 per cent.

The experiments reveal several interesting instances of resonance phenomena in the high-tension transformer circuits.

IN AN earlier paper by one of the authors[1] it was shown that within the range 20 to 90 cycles per second the frequency had a measureable effect on the voltage (maximum of the wave) at which the corona begins. The principle of the method of experiment is simple and will be repeated briefly here. The corona is formed about a wire which is stretched coaxially in a metal cylinder, the ends of the cylinder being closed by insulating bushings. Air may be let into the cylinder by a lateral tube near one end and out by a lateral tube near the other end. Immediately after leaving the cylinder the air passes over an insulated electrode which is connected to a gold leaf electroscope. The walls of the cylinder where the lateral tubes were connected were drilled with numerous small holes. The air could thus pass freely and at the same time the electrode could not be influenced electrostatically by the presence of the highly charged wire at the axis of the cylinder. As the voltage applied to the wire

1. Whitehead, TRANS. A.I.E.E., 1910, Vol. XXIX, Part II, p. 1159; and 1911, Vol. XXX, Part III, p. 1857.



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is gradually raised a value is reached at which the air around the wire is ionized, that is, becomes conducting. The electroscope, as soon as this occurs, begins to lose its charge. The cylinder was always connected to earth.

It was found that the point at which the electroscope began to leak was the same whether the air was moving through the tube or whether the air was at rest, and that initial ionization and the visual corona were always contemporaneous. It was shown too, that for a given size wire and tube under the same conditions of temperature and pressure, the corona always began when the voltage in its cycle reached a definite value and that this value was approximately the same as the maximum value of the voltage at which the electroscope first began to leak. Another result was that the electric field strength at the surface of wire when corona began was independent of the size of the tube.

The value of the voltage delivered by the high-tension side of the transformer was determined from the ratio of transformation and from oscillograms taken of the voltage impressed across the low-tension terminals of the transformer. It was assumed that the wave shape of the high-tension e.m.f. was the same as that of the low-tension e.m.f.

The uniform appearance of the corona at a definite value of voltage regardless of position on the wave would seem to indicate that the corona voltage should be independent of the frequency. This, however, was not borne out by the experiments. The corona voltage was found to decrease with increasing frequency. A curved plotted between frequency and the maximum value of the voltage wave for the critical voltage (*i.e.*, beginning of corona) showed a fairly regular decrease from 20 cycles to 90 cycles. This decrease had the same percentage value for the various sizes of wire tried. The voltage at 90 cycles was about 6 per cent lower than the voltage of 20 cycles.

The influence of frequency has been studied by comparatively few investigators, and far from completely. Peek[2], in the range 40 to 100 cycles per second, was unable to detect any influence of frequency either on the voltage at which the visual corona started or on the voltage at which the loss began. Very recently Alexanderson[3] has found that at 100,000 cycles per second, a 3-in. (76.2-mm.) spark gap between spheres 5 in. (127 mm.) in diameter breaks down at approximately the same voltage (100,000 volts)

2. Peek, TRANS. A. I. E. E., 1912, Vol. XXXI, Part I, p. 1055.
3. Alexanderson, *General Electric Review*, page 427, April 1914.

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that it does at commercial frequencies; a 5-in. gap between plane parallel plates, however, was found to break down at 30,000 volts—a much lower value than the breakdown voltage for commercial frequencies. Recent results of Weidig and Jaensch[4] indicate that for increasing values of voltage above the corona-forming voltage, the corona starts at a lower and lower and ends at a higher and higher instantaneous value; this is at variance with the observations reported in an earlier paper of this series and referred to above.

The work of the present paper was undertaken in order to extend the observations of the corona voltage over a wider range of frequency.

## Experimental Apparatus

The generator available, although structurally a unit (direct-driven) consisted in fact of two generators; one having 48 poles and the other 240 poles. At the rated full speed, 1500 rev. per min., one generator gave 600 cycles and the other 3000 cycles per second. Each machine was rated at 110 volts, 5 amperes. Two transformers were used, one rated at 500 watts, 100-10,000 volts at 133 cycles per second, and a second, employed in the larger part of the work, rated at 3000 watts at 60 cycles. The low-tension winding of the latter transformer was in two 50-volt sections, the high-tension winding was in four sections, the rated voltage per section being 6250 volts.

The high-frequency generator was driven by a d-c. 240-volt shunt motor. The field of the generator was supplied from a 120-volt storage battery. The large amount of inertia possessed by the revolving field of the generator prevented any sudden changes in speed due to changing voltage of the direct-current supply. The conditions were thus favorable to steadiness in the readings. The speed of the generator was controlled partly by the use of resistance in the motor armature circuit and partly by varying the resistance of the motor field circuit.

Speeds from normal to three-quarters normal were obtained by the use of armature resistance; speeds from three-quarters to half normal were obtained by running the motor armature from the 120-volt mains and by the use of resistance in the field circuit. It was not feasible to run the machine at any speed much below half speed, because of the large field current required by the generator, and because of speed fluctuations. Control of

4. Weidig and Jaensch, *Electrotechnische Zeitschrift*, Heft 23 and 24, 1913.

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the transformer voltage was effected by varying the field current of the generator.

The corona apparatus proper consisted, as in the earlier experiments, of a wire stretched coaxially in a metal tube. At a point equidistant from the ends of the tube were drilled numerous small holes (about $\frac{1}{8}$ in. (3.2 mm.) in diameter). The electrode, which consisted of a brass disk having the same curvature as the tube, was placed over these holes and as near the tube as could be conveniently be done without having metallic contact. A grounded metallic shield was placed around the electrode and the connection to the electroscope was made through a hole in the shield, the wire being insulated from the shield by means of a plug of sulfur. The electroscope was a very sensitive one; it gave a workable deflection of the gold-leaf when charged to a potential of 120 volts. In the earlier part of the work the ends of the tube were left open, the wire being stretched between insulating supports situated at some distance from the ends of the tube. Later the ends of the tube were closed by insulating caps, the wire passing through holes in the caps.

## The Experiments

Observations were first made on a brass wire 0.089 cm. (0.0350 in.) in diameter in a 4.9-cm. tube. The 500-watt transformer mentioned above was used. The procedure was to raise the primary voltage by increasing the field current of the generator until the electroscope began to discharge. The field current was then decreased until the leak of the electroscope stopped, and then increased again. The voltage at the instant the leak began was read by a hot-wire voltmeter, connected across the low-tension terminals of the transformer. The speed was read by a carefully calibrated tachometer. No attempt was made in these experiments to determine the wave shape, this being a matter of some difficulty at the frequencies in question. In the neighborhood of 600 cycles, the electroscope began to leak at about 80 volts, at 1400 cycles at 73 volts and finally, at 2800 cycles, at 37 volts. The decrease in voltage between 1400 and 2800 cycles was fairly regular.

It seemed highly improbable that the corona voltage actually experienced as great a change as was indicated by the above figures. To test the matter further a high-tension electrostatic voltmeter was connected across the high-tension terminals of the transformer.

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It was found that the corona voltage as indicated by the static voltmeter remained constant. The corona tube was then disconnected from the transformer and at various frequencies the voltage was adjusted so that this voltmeter always read 10 kilovolts. At 60 cycles the low-tension voltage was 82.5 volts, and at 2750 cycles, 31 volts. It was thus seen that the ratio of transformation of this transformer was *over two and one-half times* as great at 2750 cycles as it was at 60 cycles. The cause of this great change is evidently the capacity of the high-tension windings. The charging current taken by the high-tension windings, other things being equal, is directly proportional to the frequency. The reactance of these same windings is also directly proportional to the frequency. Consequently one would expect the disturbing effect of the charging current on the ratio of transformation to be, roughly, directly proportional to the square of the frequency.

That the current taken by the transformer was leading was easily shown. An electrodynamometer connected in the low-tension side indicated 5.5 amperes at 2750 cycles—ten times the value of the current taken at 60 cycles for the same high-tension voltage. The large reactance of this instrument (22 ohms at 2750 cycles) was in this instance of great advantage, because by applying the three-voltmeter method to the dynamometer and transformer the relative power factor of the two could be at once determined. The power factor of the dynamometer alone was determined by series connection with incandescent lamps (assumed non-inductive) and applying the same method. It was found that the current taken by the transformer at 2750 cycles was leading the voltage by about 60 degrees.

For further study of this disturbing influence tests were made with the 3000-watt transformer described above. The high-tension voltage was not measured, but the effect of different methods of connection of the high-tension coils was studied. All the experiments were conducted at about 2750 cycles. A few examples of the results may prove of interest. With all the high-tension windings in series, one end of the winding connected to ground and the other end open, the transformer took 3.1 amperes at 3.5 volts, the current leading the voltage by about 20 degrees. With the high-tension windings connected two in series, two in parallel, the same point being earthed as formerly, the transformer took 4.0 amperes at 33.5 volts, the current leading the voltage by about 90 degrees. In both cases the low-

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tension windings were in series. These two cases are fair samples of the results found in the course of the experiments, and indicate that the method of connecting the high-tension windings has a pronounced influence on the readings of the instruments in the primary side of the transformer.

There was also evidence that at one frequency within the range studied, the transformer was in resonance. With a certain arrangement of the high-tension windings and running at 2750 cycles the switch of the driving motor was opened. With the resulting decrease of speed and frequency, the voltage applied to the transformer and the current taken by it both began to increase and kept on increasing until it was necessary to open the transformer circuit in order not to injure the instruments. There were also indications that the principal factor in these effects was the capacity between winding and core and not beteen successive portions of the winding. It was found, for example, that the readings on the low-tension side of the transformer depended only upon the maximum voltage (from ground) reached in the high-tension winding. The effect produced by connecting all the coils in series and grounding the middle point of the winding was the same as that produced by connecting the windings two in series and two in parallel and grounding one end.

It appears probable from the results of this paper that the 6 per cent lowering of the corona voltage in going from 20 to 100 cycles reported in the second of this series of papers may be explained as a disturbance due to the capacity in the transformer; all measurements in that work were made on the low-tension side.

## Measurement of Maximum Value of Voltage

It was at once evident from the results of the tests described above that the measurements of corona voltage would have to be made on the high-tension side of the transformer. This condition, coupled with the unreliability of the oscillograph for the higher frequencies, made it impossible to obtain complete knowledge of the wave shape, except, perhaps, by the use of the cathode ray oscillograph. It is possible, however, to measure both maximum and effective values. Obviously the former is the more important, and probably the determining factor in the formation of corona. The only method available for finding the maximum value is that used by Chubb and Fortescue,[5]

5. Chubb and Fortescue, in Proc. A. I. E. E., p. 627, Feb. 1913.

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among others. The method consists essentially in applying the voltage to be investigated to a condenser and measuring the average value of the current taken by the condenser. Let $V$ represent the maximum value attained by the voltage, $C$ the capacity of the condenser and $f$ the frequency. The time taken by the voltage in passing from its maximum value in one direction, to its maximum in the other, is $\frac{1}{2f}$. In this time the current goes from zero to a maximum and back to zero again. Its average value is equal to the total charge which has passed through the circuit divided by the time taken for the charge to pass. In symbols:

$$i_{av} = \frac{1}{\frac{1}{2f}} \int_0^{\frac{1}{2f}} i\,dt = \frac{2VC}{\frac{1}{2f}} = 4fVC.$$

$$V = \frac{i_{av}}{4fC} \qquad (1)$$

In order to measure the average value of the charging current taken by the condenser, it is necessary to employ a measuring instrument of the permanent magnet type and to rectify the current before it passes into the instrument, or, what amounts to the same thing, to allow only one-half of the current wave to pass through the instrument; in this latter case the reading of the instrument must be multiplied by 2 in order to get the average value of the current. Chubb and Fortescue made use of a mechanical device in order to have only one half of the current wave pass through the measuring instrument. In the present work the use of a mechanical device was out of the question on account of the high frequencies employed. The mercury arc immediately suggests itself as a non-mechanical rectifier. The rectifying properties of the mercury arc when playing between a mercury and an iron electrode are well known. The arc permits current to flow from the iron electrode to the mercury with only a trifling drop of voltage in the arc; no current can flow in the opposite direction until the applied voltage has risen so high as to cause a vacuum discharge to pass through whatever gas may be present. The mercury arc, moreover, is a very rapid in action. It has been shown, for example, that the arc will

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be extinguished if the current supply is interrupted for as much as the ten-millionth part of a second. Thus the ionization or conductivity due to the passage of the current dies out with enormous rapidity.

In the present experiments the current taken by the condenser could not itself be used to maintain the arc, first, on account of its small value, and second, because of the necessary method of connection (see Fig. 2). As a consequence the cathode had to be kept active by an arc (maintained by direct current) playing between the cathode and an auxiliary mercury anode. The form of tube which was adopted after considerable experimenting is illustrated in Fig. 1. The tubes were made from German soft glass tubing having approximately an internal diameter of 1 cm. and walls 1 mm. thick. The iron electrode consisted of about 6 cm. of No. 30 iron wire which had been well oxidized by passing through the flame of a blast lamp. The object in making the iron electrode so small was to prevent mercury from condensing on it. In an earlier form of tube the iron electrode was much larger, with the result that mercury condensed on the electrode and dropped off. This last action interfered seriously with the proper functioning of the tube as, at every fall of a drop, an arc would be started, irrespective of the direction of the voltage acting across the gap. A small wire assumes the temperature of the surrounding mercury vapor much more quickly, consequently condensation is much reduced. The electrode was oxidized in order to prevent the amalgamation of the iron and the condensed mercury. The presence of such an amalgamated surface seems to facilitate condensation enormously. The tubes were exhausted while running until the pressure of the residual gas was less than 0.0001 mm.

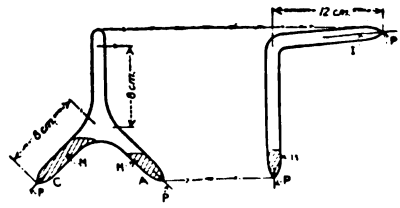


FIG. 1

P, platimum wire; I, iron wire; M, mercury; C, cathode; A, anode.

A diagram of connections is shown in Fig. 2. It will be seen that during one half of the wave the charging current of the condenser passes through one of the two tubes and during the other half through the other tube. A direct-current voltmeter was used as a current-measuring instrument. This voltmeter was in circuit with one of the tubes; consequently, in

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order to get the average value of the current its reading must be multiplied by 2. The voltmeter gave full scale deflection for a current of approximately 0.01 ampere. The 1.5-volt scale (resistance approximately 156 ohms) of the instrument was used; there was no difference in reading, however, when the 150-volt scale was used instead. The instrument gave the same reading no matter with which tube it was in circuit; the reading was also unaffected by the presence of a similar instrument in series with the other tube. Each tube, moreover, was carefully tested for the degree of rectification. When the arc was playing between the two mercury electrodes a 240-volt difference of potential was applied between the mercury cathode and the iron electrode, suitable resistances being in the circuit for protection. When the iron electrode was positive with respect to the mercury cathode there was passage of current and the drop of potential across the tube was about 50 volts,

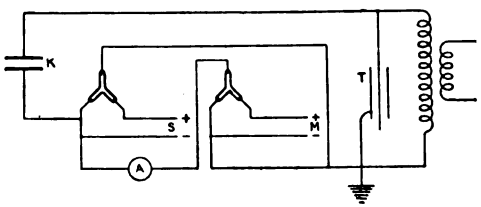


FIG. 2

A, voltmeter; S, special generator; K, condenser; M, city mains; T, corona tube.

independent of the value of current. When the iron electrode was negative with respect to the mercury cathode, the voltmeter showed no deflection and the use of a sensitive galvanometer showed that the current flowing was not greater than the five-millionth part of an ampere. As the tubes were used to rectify currents of the order of magnitude of 0.01 ampere the rectification was thus practically perfect. Finally, the tubes were set up in series with a condenser, as shown in Fig. 2, and tested at various frequencies from 45 to 75 cycles. The assumption was made that in this range of frequencies the ratio of transformation remained constant and that the wave shape of the high-tension e.m.f. was the same as that of the low-tension e.m.f. The low-tension wave form was taken from oscillograms. The values of the maximum high-tension voltage as measured directly by the mercury tubes, and as calculated from the ratio of transformation and low-tension read-

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ings, were the same, within the probable error of the measurements.

### Measurement of Effective Value of Voltage

While the knowledge of the maximum value of the voltage so obtained seemed of greatest importance, it was also considered desirable to determine the effective value so as to obtain an approximate indication of the wave form, and ratio of transformation. Concerning minor irregularities on the wave nothing, of course, can be said. An electrostatic voltmeter seemed to be the most suitable instrument. An instrument was needed which would give the effective value of the voltage to $\frac{1}{2}$ of one per cent or better, and which at the same time could be easily damped. These requirements suggested a Crémieu electrostatic-electrodynamic balance. The principle of this instrument is as follows: The voltage to be measured is applied to two disks, one of which is mounted at the end of one arm of a balance beam, the other disk being fixed and in proper relation to the first. The attraction between these disks is balanced by the repulsion exerted between two coils, one of which is fixed at the other end of the balance beam. A constant direct current from some suitable source is passed through these two coils, which are in series. This current is adjusted until the balance is in equilibrium in the same position that it occupies when no electric or magnetic forces are acting. The moment of the electric forces about the knife edge varies directly as the square of the voltage between the disks, and the moment of the magnetic forces varies directly as the square of the current flowing in the coils. Consequently when the balance is brought into the proper position of equilibrium the voltage between the disks is directly proportional to the current flowing in the coils. If, as in the present case, the voltage is alternating, the moment is proportional to the average square of the voltage, which is by definition the square of the effective value. Hence the effective value of the voltage is directly proportional to the current flowing in the coils.

The authors were fortunate in having available a balance beam with a fine agate knife edge, and the usual mounting. All magnetic material had been carefully excluded from the construction of the balance and its glass case. The disks were of aluminum and were 10 cm. in diameter. The distance between the fixed disk and the moving disk was 3.2 cm. The

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moving coil consisted of 50 turns of No. 18 copper wire. The fixed coil had 1200 turns of No. 18 wire. The current was led into the moving balance system by means of two silver strips each 0.0013 cm. (0.0005 in.) thick, 1 mm. wide, and 6 cm. long. The points of support of a strip were 4 cm. apart, so that the strip had a very considerable sag. These silver strips would carry about 3.5 amperes before burning out. The largest current they were ever called on to carry was about 1 ampere; with this value of the current the heating of the strips was never enough to cause any disturbance of the balance due to air currents. The strips also had no effect on the sensibility of the balance, nor on the stability of the zero point. In using the balance, current for the coils was taken from a storage battery. When the voltage applied to the disks was steady, readings could be repeated to within $\frac{1}{8}$ of one per cent. When the voltage was unsteady, differences as great as one per cent frequently occurred. The balance was standardized at low frequencies, using the ratio of transformation and low-tension wave form.

### Influence of Temperature and Pressure

The influences of pressure and of temperature upon the corona have not been investigated for frequencies above the neighborhood of 60 cycles. While it does not appear probable from the theory of ionization by collision that these influences would suffer any change up to 3000 cycles, it is nevertheless a matter of some uncertainty. Therefore, in order to determine the influence of frequency alone, it was necessary to make observations over the whole range of frequency within a period of time during which the pressure and temperature remained reasonably constant. Three hours was adopted as the length of such a period. This procedure made rather small the number of different frequencies at which it was possible to make observations, but the number of points obtained was sufficient to give a good knowledge of the variation with frequency. In order to shorten the time required for each reading only the maximum of the high-tension voltage wave was read when making observations on the corona. The effective values corresponding to the maximum voltages used were determined after the corona readings, thus greatly facilitating the work as the effective values of all the different voltages used over the whole range of frequencies were readily determined in a

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day. Referring again to Fig. 2, the voltage on the low-tension side of the transformer was read by a Hartmann and Braun hot-wire voltmeter, the series resistance of which was specially wound to avoid change in resistance with frequency. The speed of the generator was read by a carefully calibrated tachometer, accurate within ½ to 1/10 of one per cent, depending on the part of the scale used.

## Calibration of Condensers

The condensers used were of the Moscicki type; the dielectric was glass and the condensers were filled with oil to avoid corona at the edges of the metallic coatings. Each condenser had a capacity of about 0.002 microfarad. Now the range of frequency used was from 60 to 3000 cycles, a 50-fold increase. A glance at equation (1) will show that if $V$ stays approximately constant over this range (as it actually does) $iav$ will be proportional to the frequency for constant capacity. This state of affairs would mean an enormous variation of the accuracy with the frequency. In order to avoid such a condition the capacity must be varied with the frequency in such a way as to keep the needle of the current-measuring instrument in a suitable part of the scale. This was done by using one condenser at 60 cycles, seven condensers in series for the range from 300 to 600 cycles, and all sixteen condensers in series for the range from 1500 to 3000 cycles. Even with the capacity reduced as much as possible by this means, it was impossible with the larger sizes of wires to go much beyond 1500 cycles, because the rectified current became larger than could be measured by the voltmeter employed; the use of a shunted instrument was, of course, out of the question.

The corona voltage at 60 cycles has been often observed; consequently it was sufficient in the present work to determine how the corona voltage varied with frequency. To this end only the *relative* values of the capacities of the condensers need be known. A special motor-driven generator, excited by a storage battery, furnished alternating current at about 45 cycles. The voltage was measured by an electrodynamometer-type voltmeter. The frequency was measured by a Hartmann and Braun vibrating-reed frequency meter. Condenser No. 1 was put in position in the connections of Fig. 2 and the low-tension voltage, frequency, and rectified current read. From seven to nine observations were made on each condenser. Then,

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keeping the frequency, excitation, and all other conditions the same, No. 1 condenser was disconnected and No. 2 connected in its place; then No. 3, and so on for all sixteen condensers. Since the condensers were of approximately the same capacity and the conditions were kept constant, the maximum value of the high-tension voltage was directly proportional to the effective value of the low-tension voltage, and consequently the value of low-tension voltage could be substituted for $V$ in the formula

$$C = \frac{i_{av}}{4fV}$$

in order to find the comparative values of the capacities. The capacity of condenser No. 1 was taken as the unit. The capacity of the condensers when connected in series could be calculated by the usual formula. The needle of the direct-current instrument vibrated with the frequency of the rectified current, the amplitude being about one-half of a division; on this account the accuracy of the reading was only $\frac{1}{2}$ per cent. The frequency could be read to $\frac{1}{2}$ per cent and the alternating voltage to 0.1 per cent. The accuracy of any one reading was consequently about 0.7 per cent. Since from seven to nine readings were taken, the final accuracy attained was about 0.3 per cent. Repeated measurements on one condenser showed that this was actually the order of accuracy attained.

### Sizes of Wires and Tubes

Two sizes of corona tubes were used in the course of the experiments, one having a diameter of 4.58 cm. and the other a diameter of 6.35 cm. The diameters of the wires used were as follows: 0.317 cm. (0.1249 in.), 0.234 cm. (0.0924 in.), 0.194 cm. (0.0763 in.), 0.164 cm. (0.0644 in.), 0.106 cm. (0.0418 in.), 0.089 cm. (0.0350 in.). All of these sizes were of brass, except the wire 0.194 cm. in diameter, which was of tool steel. The smaller sizes were made straight by heating with an electric current while under tension. The larger sizes were rods which needed no such treatment. Each time before being used the wire was polished with the very finest emery paper until the latter became glazed with brass. A final polish was given with tissue paper. This treatment produced a very good polish. In the earlier part of the work the tube was left open at the ends; for the most part, however, the ends were closed with insula-

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ting caps. No difference between the two cases could be detected.

## Accuracy of Observations

The rectified current could be read to 0.1 per cent at frequencies of 300 and more, the needle standing without vibration. The speed could be read always to ½ per cent and generally still more closely. The capacity of the condensers had been determined to 0.3 per cent. Consequently any one observation of the maximum voltage at 300 cycles and over was accurate to 0.6 per cent. At 60 cycles the rectified current could be read to ½ per cent, the frequency (the generator was not readily accessible) to ½ per cent, and the capacity, as before, was determined to 0.3 per cent. The accuracy was consequently at 0.8 per cent. For convenience, the current required to deflect the direct-current voltmeter one scale division, and the capacity of condenser No. 1, were chosen as units of observation. The formula for the maximum voltage then becomes

$$V = k \frac{E}{f C} \qquad (2)$$

$k$ being a constant of the apparatus and $E$ the reading of the voltmeter. It was assumed, on the basis of information from the Bureau of Standards, that the capacity of the Moscicki condenser varies only a fraction of one per cent over the range of frequency investigated.

## The Observations

It was possible in the three-hour period mentioned above, to make one or sometimes two sets of observations at 60 cycles, two sets in the neighborhood of 600 cycles and several sets between 1500 cycles and the maximum frequency obtainable as limited by the rated speed of the machine or more often by the capacity of the direct-current instrument. Each set of readings consisted of from five to twelve observations of the corona voltage. As a general thing, repeated sets of observations agreed very closely, that is, within a few tenths of one per cent, but sometimes they would differ by as much as 2 per cent. These differences could not be accounted for. The constancy of the corona voltage was not always such that full advantage could be taken of the accuracy of the method, and apparent constancy of conditions. The following table is an

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example of a set of readings in which the agreement was very good:

| D-C. Instrument | Low-tens. voltage of trans. | Speed in rev. per min. |
|---|---|---|
| 140.2 | 102.3 | 968 |
| 140.5 | 102.3 | 968 |
| 140.0 | 102.0 | 973 |
| 140.0 | 102.7 | 968 |
| 140.0 | 102.1 | 968 |
| 140.0 | 102.1 | |
| 139.5 | 102.1 | 969 |
| 139.3 | 101.5 | |
| 139.8 | 102.1 | 968 |

The following table is an example of a rather bad set:

| D-C. Instrument | Low-tens. voltage of trans. | Speed in rev. per min. |
|---|---|---|
| 89.0 | | 1050 |
| 91.0 | Off scale | 1038 |
| 90.8 | | 1038 |
| 91.0 | *i. e.*, over 130 volts. | 1038 |
| 90.3 | | 1038 |
| 90.9 | | 1038 |
| 91.9 | | 1037 |

The results for the tube 4.58 cm. in diameter are given in Table I, and those for the 6.35-cm. tube are given in Table II. The voltages given were calculated by means of formula (2). These results are plotted in Figs. 3 and 4 respectively. In these figures the points of each set are connected by straight lines in order to make interpretation easier. Each point represents a series of from five to twelve observations.

Table III gives the values of effective high-tension voltages, ratio of transformation, and peak factor, that is, ratio of maximum to effective high-tension voltage, for various voltages and frequencies over the entire range explored. The maximum values are those observed with the condenser and mercury-arc rectifier apparatus as described. The peak factor at 60 cycles was about 1.48. The range of peak factors obtained in the course of the observations consequently is from 1.66 to 1.27. The wave of voltage, therefore, did not depart greatly from

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TABLE 1

CORONA VOLTAGES FOR WIRES IN TUBE 4.58 CM. IN DIAMETER.

| Diam. of wire | Series of observations | Frequency in cycles per second | Voltage / $k$ |
|---|---|---|---|
| 0.317 cm. (0.1249 in.) | | 59.0 | 1.242 |
| | | 1338 | 1.191 |
| | | 1680 | 1.202 |
| 0.234 cm. (0.0924 in.) | 1 | 59.2 | 1.079 |
| | | 558 | 1.061 |
| | | 575 | 1.063 |
| | | 1368 | 1.048 |
| | | 1372 | 1.060 |
| | | 1914 | 1.042 |
| | | 1948 | 1.043 |
| | 2 | 58.5 | 1.081 |
| | | 583 | 1.039 |
| | | 1362 | 1.037 |
| | | 1370 | 1.053 |
| | | 1826 | 1.037 |
| | | 1968 | 1.047 |
| | 3 | 58.0 | 1.076 |
| | | 585 | 1.040 |
| | | 1368 | 1.038 |
| | | 1672 | 1.043 |
| | | 1970 | 1.041 |
| | | 2076 | 1.042 |
| 0.194 cm. (0.0763 in.) (tool steel) | 1 | 59.5 | 0.998 |
| | | 569 | 1.960 |
| | | 2006 | 0.976 |
| | 2 | 58.8 | 0.999 |
| | | 566 | 0.977 |
| | | 567 | 0.973 |
| | | 1336 | 0.986 |
| | | 1884 | 0.982 |
| | 3 | 60.5 | 0.995 |
| | | 590 | 0.950 |
| | | 590 | 0.951 |
| | | 1370 | 0.968 |
| | | 1410 | 0.963 |
| | | 1692 | 0.967 |
| | | 2058 | 0.967 |
| | | 2122 | 0.958 |
| 0.164 cm. (0.0644 in.) | 1 | 59.6 | 0.904 |
| | | 568 | 0.877 |
| | | 576 | 0.893 |
| | | 1376 | 0.895 |
| | | 1418 | 0.888 |
| | | 1754 | 0.885 |
| | | 2176 | 0.884 |
| | | 2412 | 0.880 |
| | 2 | 58.9 | 0.919 |
| | | 587 | 0.882 |
| | | 1378 | 0.886 |
| | | 1396 | 0.886 |
| | | 1730 | 0.878 |
| | | 2110 | 0.880 |
| | | 2372 | 0.875 |
| | 3 | 58.3 | 0.928 |
| | | 584 | 0.880 |
| | | 1368 | 0.885 |
| | | 1674 | 0.894 |
| | | 2054 | 0.890 |
| 0.106 cm. (0.0418 in.) | 1 | 59.5 | 0.758 |
| | | 573 | 0.738 |
| | | 575 | 0.738 |
| | | 2640 | 0.737 |
| | | 2650 | 0.739 |
| | | 2822 | 0.728 |
| | 2 | 59.1 | 0.748 |
| | | 598 | 0.728 |
| | | 598 | 0.729 |
| | | 1416 | 0.716 |
| | | 2134 | 0.725 |
| | | 2908 | 0.700 |
| | | 2966 | 0.700 |
| 0.089 cm. (0.0350 in.) | 1 | 59.5 | 0.689 |
| | | 60.0 | 0.683 |
| | | 558 | 0.686 |
| | | 570 | 0.680 |
| | | 2822 | 0.666 |
| | 2 | 59.4 | 0.683 |
| | | 573 | 0.683 |
| | | 1406 | 0.680 |
| | | 2792 | 0.677 |

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the sine shape. The ratio of transformation of the transformer increased between 60 cycles and 2958 cycles by about 30 per cent.

TABLE II

CORONA VOLTAGES FOR WIRES IN TUBE 6.35 CM. IN DIAMETER.

| Diam. of wire | Series of observations | Frequency in cycles per second | Voltage / $k$ | Diam. of wire | Series of observations | Frequency in cycles per second | Voltage / $k$ |
|---|---|---|---|---|---|---|---|
| 0.317 cm. (0.1249 in.) | 1 | 59.8 | 1.370 | 0.164 cm. (0.0644 in.) | 1 | 58.6 | 0.994 |
| | | 578 | 1.313 | | | 585 | 0.955 |
| | | 1294 | 1.338 | | | 1372 | 0.961 |
| | | 1622 | 1.313 | | | 1740 | 0.952 |
| | | | | | | 2102 | 0.959 |
| | 2 | 59.4 | 1.362 | | 2a (without series inductance in low-tension circuit.) | | |
| | | 274 | 1.402 | | | 272 | 1.031 |
| | | 346 | 1.373 | | | 274 | 1.037 |
| | | 423 | 1.361 | | | 347 | 1.031 |
| | | 502 | 1.366 | | | 473 | 0.982 |
| | | 566 | 1.360 | | | 528 | 1.016 |
| | | 1298 | 1.350 | | | 584 | 1.004 |
| | | 1440 | 1.350 | | | | |
| | | 1638 | 1.336 | | | | |
| 0.234 cm. (0.0924 in.) | 1 | 58.3 | 1.198 | | 2b (with series inductance in low-tension circuit.) | 275 | 1.039 |
| | | 585 | 1.147 | | | 346 | 1.019 |
| | | 1360 | 1.148 | | | 388 | 0.996 |
| | | 1684 | 1.161 | | | 423 | 0.982 |
| | | | | | | 463 | 1.010 |
| | 2 | 58.9 | 1.186 | | | 528 | 1.011 |
| | | 284 | 1.223 | | | 570 | 1.019 |
| | | 316 | 1.212 | | | | |
| | | 354 | 1.191 | 0.106 cm. (0.0418 in.) | 1 | 58.7 | 0.796 |
| | | 467 | 1.091 | | | 59.4 | 0.795 |
| | | 529 | 1.166 | | | 594 | 0.765 |
| | | 566 | 1.191 | | | 1388 | 0.776 |
| | | 570 | 1.181 | | | 1766 | 0.770 |
| | | 1098 | 1.166 | | | 2134 | 0.775 |
| | | 1460 | 1.170 | | | 2644 | 0.761 |
| | | 1848 | 1.151 | | | | |
| | 3 | 58.1 | 1.175 | | | | |
| | | 58.6 | 1.191 | | | | |
| | | 274 | 1.191 | | | | |
| | | 342 | 1.197 | | | | |
| | | 421 | 1.164 | | | | |
| | | 469 | 1.122 | | | | |
| | | 527 | 1.159 | | | | |
| | | 570 | 1.174 | | | | |
| | | 1392 | 1.174 | | | | |

## DISCUSSION

Referring to Figs. 3 and 4, it will be noticed that there is a considerable amount of irregularity in the locations of the successive points with reference to smooth curves. This

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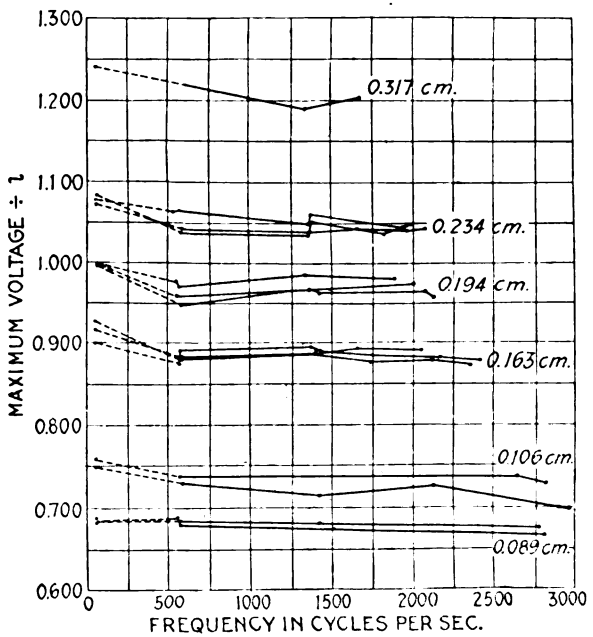


FIG. 3—CORONA VOLTAGES. TUBE 4.58 CM. IN DIAMETER.

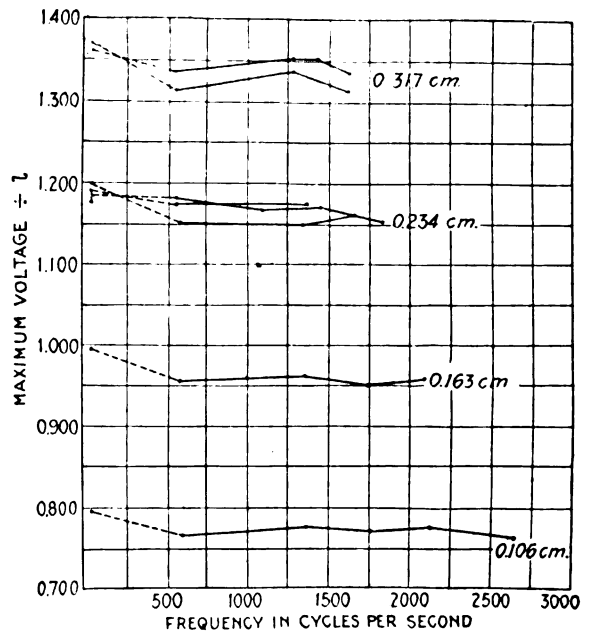


FIG. 4—CORONA VOLTAGES: TUBE 6.35 CM. IN DIAMETER.

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result has been a surprise and a disappointment. Much care was taken to obtain the best conditions of accuracy in all of the instruments used. Further, during any one set of observations, there was never any indication of varying conditions. Consecutive readings taken in any one set of conditions repeated themselves accurately for the most part, and in altering the frequencies there was no suggestion, during the observations, of unstable conditions (except in one region, as described below). No cause could be found for the difference between the obser-

TABLE III

RATIO OF TRANSFORMATION AND PEAK FACTOR

| Frequency in cycles per second | Low-tension voltage | Ratio of trans. $R$ | Peak factor $P$ | Frequency in cycles per second | Low-tension voltage | Ratio of trans. $R$ | Peak factor $P$ |
|---|---|---|---|---|---|---|---|
| 58.4 | 90.6 | 1.000 | 1.000 | | | | |
| 592 | 54.0 | 2×1.049 | 0.860 | 58.0 | 89.9 | 1.000 | 1.000 |
| 594 | 40.1 | 2×1.048 | 0.869 | 274 | 125.5 | 1.007 | 1.120 |
| 1382 | 62.0 | 1.033 | 0.920 | 274 | 115.5 | 1.007 | 1.120 |
| 1370 | 93.4 | 1.040 | 0.946 | 350 | 101.5 | 1.012 | 1.028 |
| 1732 | 92.6 | 1.074 | 0.920 | 344 | 130.0 | 1.017 | 1.078 |
| 2136 | 50.2 | 1.100 | 0.913 | 417 | 130 | 1.017 | 1.028 |
| 2112 | 73.2 | 1.131 | 0.921 | 427 | 53.0 | 0.991 | 1.037 |
| 2080 | 94.0 | 1.148 | 0.923 | 471 | 37.1 | 2×1.027 | 0.907 |
| 2392 | 46.5 | 1.189 | 0.912 | 458 | 65.8 | 2×1.011 | 0.888 |
| 2264 | 78.5 | 1.158 | 0.923 | 522 | 75.5 | 2×1.014 | 0.889 |
| 2958 | 44.9 | 1.310 | 0.908 | 526 | 51.5 | 2×1.031 | 0.885 |
| | | | | 526 | 32.5 | 2×1.052 | 0.881 |
| | | | | 558 | 74.5 | 2×1.038 | 0.894 |
| | | | | 556 | 61.0 | 2×1.032 | 0.896 |
| | | | | 560 | 46.9 | 2×1.021 | 0.896 |
| | | | | 556 | 33.3 | 2×1.037 | 0.900 |

$P$ = peak factor of 60 ~ generator = 1.48 approx.
$R$ = ratio of transformation at 60 ~ = 125.1 : 1 or 250.2 : 1.

vations over the same range from one day to another. Temperature and pressure were eliminated as possible causes for these differences by successive series of observations under the same conditions, approximately, as to temperature and pressure.

There seems, however, to be no doubt that there is a decrease in the corona voltage, amounting to about 3 or 4 per cent, in increasing the frequency from 60 cycles to 2000 cycles or over. This decrease is apparently more pronounced for the larger sizes of wire.

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It will be noticed that the points showing most serious departure from a regular curve are those for frequencies within the range 300 to 600 cycles. The observations in this range have caused much trouble and for this reason the curves have been drawn in dotted lines indicating uncertainty as to the observations. As nearly as could be determined, there was a tendency for the maximum corona voltage to take a sharp dip in passing through this range. There were, however, several accompanying conditions of experiment which may well account for the irregular results. For example, the connection of the high-tension winding of the transformer had to be altered in this range in order to make the necessary change in the corona voltage. Attention has already been drawn to the influence of this change on the charging current of the windings. It will be seen from Table III that there is evidence of a difference in the high-tension wave form for the series connection and the parallel connection of the two halves of the high-tension winding. Further, at about 425 cycles, and within a certain range of field excitation of the generator, there was a pronounced evidence of resonance in the high-tension circuit. On the smallest possible change in the field current of the generator, the reading of the d-c. instrument, indicating the maximum voltage, increased sharply from 35 to 80. Observations taken at this frequency on a larger wire and for values of voltage above the unstable region, showed no unusual conditions other than a slight irregularity of voltage which was readily damped out by series inductance in the low-tension circuit.

Still further evidence of abnormal conditions in the range 300 to 600 cycles was found in the different results obtained in the series and parallel connections of the high-tension winding Between 270 and 425 cycles with the series connection a spark would pass between wire and outer tube at a voltage only about $\frac{1}{2}$ that required to produce corona when the high-tension winding was connected in parallel. The same phenomenon was observed in the range 450 to 600 cycles, with the exception that the parallel connection gave the spark at low voltage. This spark was intermittent, apparently localized, and very different from the usual uniform corona. The impression made was that there was a series of short impulses of abnormally high voltage.

While it is evident, therefore, that there were a number of abnormal conditions surrounding the observations in the region 300 to 600 cycles, there is no obvious reason why, if the conditions

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were steady, the maximum value of voltage could not have been picked out by the mercury arc peak voltmeter. There is every indication that the mercury arc is instantaneous in action. Nevertheless, there seems to be no other conclusion than that the conditions of resonance described above introduced very brief voltage impulses of high value which the mercury arc and condensers did not pick out. Considerable variation was obtained in the wave form by connecting the armatures of the two generators in series, thus obtaining a prounounced fifth harmonic. There was no resulting variation of the corona voltage; such variation, however, could hardly be expected unless the frequencies were far higher than 3000 cycles.

The corona from 1500 cycles upward appears also to differ qualitatively from that at lower frequencies. It is a common observation at 60 cycles that the gold-leaf of the electroscope descends in a jerky fashion when corona voltage is reached. The time taken for complete discharge is about 30 seconds. This has been attributed to the exact constancy of the corona voltage and the usual slight variation of the impressed voltage. From 300 to 600 cycles the electroscope discharged quickly but steadily, the time for discharge being one or two seconds. From 1500 to 3000 cycles the electroscope discharged in a very small fraction of a second, the gold-leaf descending practically instantaneously. There is absolutely no indication of leak before any of these observations.

A further interesting phenomenon at the higher frequencies was the vibration of the wire in the case of the open tube, when the points of suspension were some distance beyond the ends. At 1500 cycles the presence of corona caused the wire to vibrate greatly. There was no vibration before the appearance of the corona. The tension on the wire was altered through a wide range, but the vibration persisted unchanged. There is apparently, therefore, no connection between the frequency of the voltage and the natural period of vibration of the stretched wire. At 60 cycles the wire remained perfectly steady, even when surrounded by a strong corona. These vibrations, therefore, are apparently forced vibrations due to some property of the corona.

In considering the possible influence of the frequency on the appearance of corona in terms of the theory of secondary ionization or ionization by collision, there are three possible ways in which this influence might act: (1) The conditions of stable equilibrium

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of the systems of vibrating electrons within the atom of the gas would be affected in different degrees by periodic electric forces of different frequencies. (2) With increasing frequencies the time during which a single free moving electron is acted on by the electric force in one direction would be less; consequently the velocity acquired and energy available for ionization by collision would be less. (3) It has been suggested that the corona occurs when the density of ionization in the gas at the surface of the wire reaches a certain value. This increase in density results from the passage inward of electrons from a distance. As they move in they create more ions by collision. More ions are created on the inward path than are lost by recombination during the reverse half of the alternating cycle. At higher frequencies the rate at which the ions would reach the wire would probably be lowered, thus demanding a higher voltage for the appearance of corona.

Of these three possible methods of explanation the first two are apparently untenable, certainly for the range of frequencies investigated in these experiments, by reason of the fact that the periods of vibration within the atom and the time during which an electron passes from one collision to another, are infinitesimally small compared with the time of reversal of the electric force at the frequencies investigated.

The experiments were carried out in the Physical Laboratory of the Johns Hopkins University. The authors wish to acknowledge the valuable assistance of Professor A. H. Pfund in connection with the mercury lamps and of Mr. M. W. Pullen at various times throughout the work.

## Summary

The most important results of the work are as follows:

(1) The corona voltage at 2000 cycles is lower by 3 or 4 per cent than it is at 60 cycles.

(2) The corona in the range 300 to 3000 cycles has a number of qualitative differences from that at 60 cycles.

(3) Convenient methods for measuring high-tension maximum and effective voltages at frequencies up to 3000 cycles have been devised.

(4) An instance of resonance due to the capacity of the high-tension windings of a transformer is recorded.

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# SPHERE GAP DISCHARGE VOLTAGES AT HIGH FREQUENCIES

BY J. CAMERON CLARK AND HARRIS J. RYAN


## ABSTRACT OF PAPER

The paper describes a series of experiments made by the authors to determine the values of steady high-frequency, high-voltage currents required to discharge between seven-inch copper spheres in air, at ordinary temperatures and barometric pressures. A 15-kw. arc generator was used as the source of high-frequency sustained high voltage, and the apparatus employed in securing and measuring currents of 123,000, 255,000 and 612,500 cycles is described in detail.

The sphere-gap standard consisted of electrolytic copper spheres mounted on the ends of brass tubes in treated wooden frames, and the gap lengths were accurately determined by means of calipers and micrometer screw or steel scale.

The results obtained are given in Tables II and III and are also charted in curves I and II, Fig. 5. The 123,000-cycle values show a right line relation between sphere gaps and discharge voltage, which line, when extended, passes through the origin. The high-frequency voltages are almost uniformly 4.5 kv. below the 25-cycle voltages observed by Chubb and Fortescue.


## INTRODUCTION

THE predatory character of high-frequency currents due to accidental causes on transmission lines is now generally recognized, especially with reference to insulation. The modern high-power radiotelegraph has encountered occasional difficulty in the maintenance of insulation that is also stressed with high-frequency high voltage. These facts have emphasized the need of more quantitative knowledge of high-frequency phenomena. To obtain this knowledge many laboratory studies and measurements will have to be made to provide more conclusive data and trained mental equipments required to interpret causes of insulation failure and to eliminate them.

To aid in these matters we have undertaken to determine the values of steady high-frequency high voltages required to discharge between seven-inch (17.7-cm.) copper spheres, in air, at ordinary temperatures and barometric pressures.



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## High-Frequency Sustained High-Voltage Source

A 15-kw. Poulsen-Federal arc generator was used. See Fig. 1. The arc is drawn in a powerful magnetic field and surrounded by water-cooled illuminating gas. A slowly-rotating carbon rod forms the cathode, and a water-cooled bronze lug forms the anode. The characteristics of this particular arc have not as yet been fully determined. At 17.6 amperes direct current through the arc and 12.5 amperes alternating current at 123,000 cycles per second in the oscillating circuit the arc is stable at 1200 continuous volts. Under these conditions the resistance ballast at $R$ is all cut out, and the power

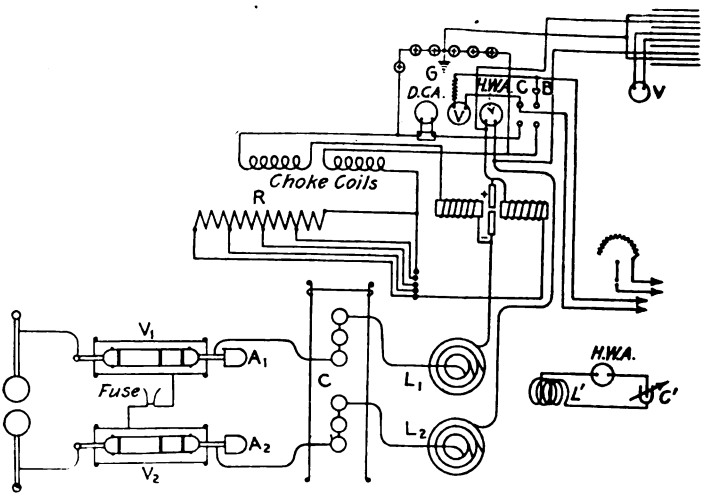


Fig. 1

consumed in the oscillating circuit is chiefly that lost in the carborundum safety resistance rods, $SR$, in series with the sphere gap. This power amounts to about one kw. There are two of these rods, each $8\frac{3}{4}$ in. (222.25 mm.) long and $\frac{3}{4}$ in. (19.05 mm.) in diameter. The charging current taken by the seven-inch (17.7-cm.) spheres at 123,000 cycles is sufficient to maintain the rods at a bright cherry-red temperature.

The insulation of the field coils of the arc generator must be extra heavy as the duty put upon it is severe. The outer terminals of the coils are connected to the anode and cathode of the arc. Correspondingly, the inner terminals are connected to the inductances that protect the direct-current generator

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from " static ". Adjustable static arrester gaps shunt these field coils to short circuit the " kick " of the field when the arc breaks. The arc will break occasionally, stopping the current through the field coils with suddenness. The discharge from these field coils will puncture their own insulation and that of the direct-current generators if such inductances and dischargers are not used. For greater safety in this regard, a series of carbon-filament incandescent lamps connects across the terminals of the generator. The middle of the series is grounded. Two 7.5-kw., 600-volt direct-current generators furnish current to the arc-generator. They are connected in series, with their mid-connection grounded. The first machine is separately excited from a 125-volt source. The 600-volt field of the second generator is excited with current taken from the armature of the first generator. Thus a rheostat in the field of the first generator controls the total direct-current supply voltage. This rheostat is mounted so that one can conveniently use it to adjust the direct-current supply voltage when he is starting the arc generator or adjusting its action.

The arc generator equipment includes one 50-ampere, direct-current ammeter showing the average direct current drawn from the continuous-current supply generators; one 30-ampere Hartmann and Braun " hot-band " ammeter measuring the high-frequency amperes circulating in the oscillating circuit; one voltmeter for reading the continuous-current supply voltage; and a high-frequency voltage gage connected across the arc to enable one to know the voltage duty demanded of the arc to set up a given current in the oscillating circuit. The last instrument is easily made by connecting a one-ampere hot-wire ammeter in series with two pairs of common tin sheets $\frac{1}{2}$ in. (12.7 mm.) separation, functioning as a condenser, and connected across the arc. The charging current taken by such condenser as indicated by the hot-wire ammeter is roughly proportional to the high-frequency voltage duty demanded of the arc. Such voltage is decidedly of irregular wave form so that this instrument functions simply as a *voltage gage*.

The inductance in the oscillating circuit is made up of approximately 2000 ft. (609.6 m.) of $\frac{1}{4}$-in. (6.3-mm.) soft copper tubing, forming six helices of 25 turns each. Each helix is mounted on six hard-rubber rods. The helices have graded diameters so that they may be telescoped to form one six-helix inductance or a pair of inductances of three helices each. The

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travel of the turns is the same for all helices,—an important matter when these large inductances are to be formed by telescoping. When the travels are not the same, *i.e.*, when they reverse from layer to layer as in the ordinary solenoid, the distributed capacity of the inductance is broken into chunks causing turbulent interference with the growth of the oscillating current. In a nest of helices the circuit leads through the first from the bottom turn to the top turn, thence downward to the bottom turn of the next helix, then out at the top, and again in at the bottom of the next, and so on through the whole set. Oscillating currents are easily driven through inductances of this sort when connected in series with suitable condensers. Even with this favorable construction the helices may not be nested in a single set because the duty demanded of the arc will easily exceed its voltage capacity before a fair value of high-frequency current has been set up. It is necessary to mount the helices in two sets, preferably of equal inductances. Then, when a single condenser is connected symmetrically between the two inductances, and in series therewith, the phase displacements that the oscillating currents encounter with respect to the arc are opposed and balanced. The high-frequency voltage duty demanded of the arc is correspondingly light. Without resorting to delicate balancing, 50,000 volts and 12.5 amperes at a frequency of 123,000 cycles per second may be developed in this apparatus. With greater care in balancing than we have so far employed, higher oscillating voltages can doubtless be developed.

The main condenser in the oscillating circuit is made up as shown at *C* in the diagram of the complete outfit given in Fig. 1. Each electrode is formed of cylinders of galvanized sheet iron seven ft. (2.1 m.) long and five in. (127 mm.) in diameter, equipped with hemispherical ends. They are also equipped with hooks and eyes so that chains of parallel cylinders may thus be formed. The capacity can be increased or decreased by attaching and detaching one or more of these cylinders from each of the two electrode chains. This feature enables the capacity in the oscillating circuit and, therefore, the frequency, to be varied over wide limits. At present this main condenser is equipped with a chain of four cylinders at each electrode. The chains hang in a vertical plane between a pair of neutral plates forming a hood about the capacity cylinders as shown in Fig. 1. The frames of these plates are made of common

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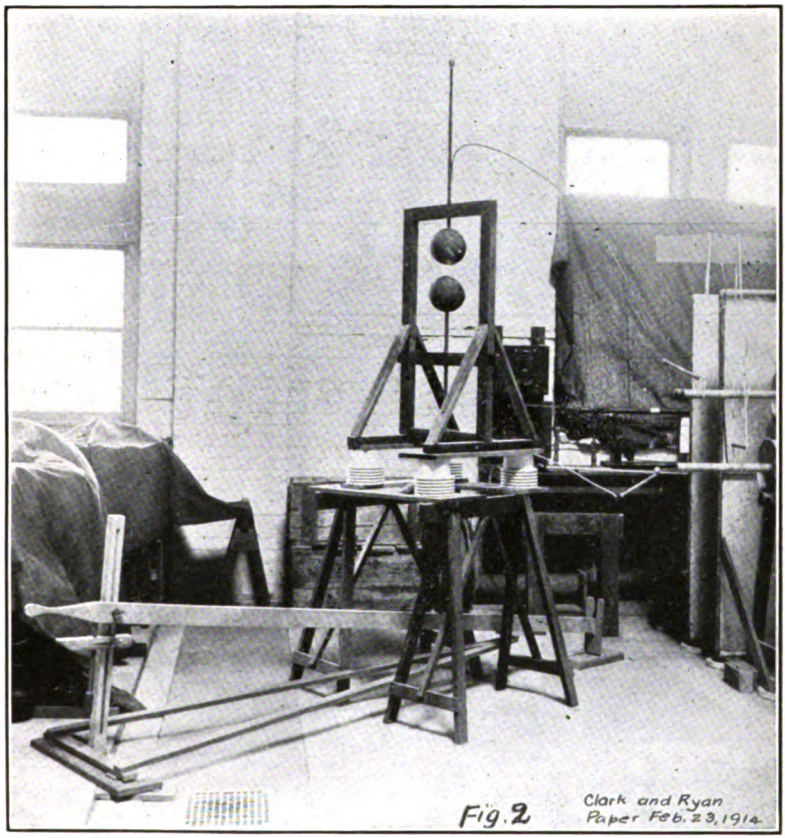


FIG. 2

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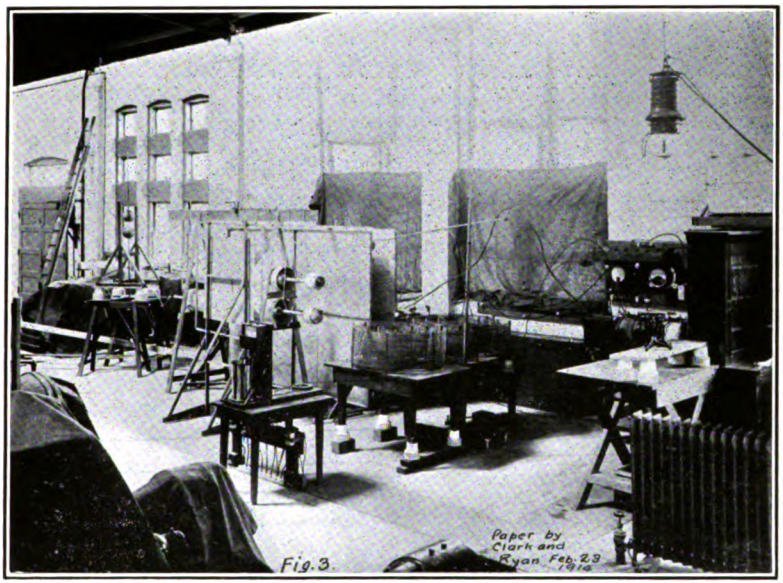


FIG. 3

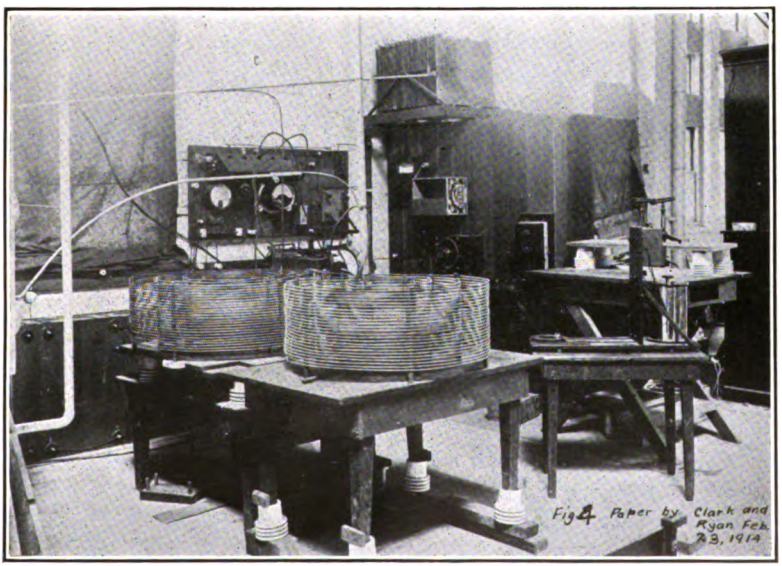


FIG. 4

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galvanized iron pipe, $\frac{3}{4}$ in. (19.05 mm.) internal diameter; the bodies of the plates are constructed of galvanized iron, 23-mil sheets. The plates are tied together with a conductor. They are insulated from ground for a small portion of the total oscillating voltage, for unless special care is taken there is some unbalancing that sets up a potential between the plates and ground. The illustrations, Figs. 2, 3 and 4, give an idea of the actual manner in which the above parts of the generating equipment are formed and arranged. To the capacity of the main condenser there is necessarily added the capacity of the concentric-cylinder voltmeter condenser, $V_1$ $V_2$; to be considered later.

In the final stage of the present undertaking, the number of helices was doubled by placing the six copper tubular helices in one nest and by the addition of a set of six helices of the same size, in which the conductor used is a " flat magnet wire " 0.34 by 0.04, in (8.6 by 1 mm.) in section. The latter set was made up, primarily, to serve as a protective inductance at the main terminal of a low-frequency high-voltage series of transformers, the other main terminal being grounded. However, by giving the helices of this set proper dimensions they could be used along with the regular set for the generation and measurement of higher voltages at lower frequencies in the standardization of the sphere-gap voltmeter. When using the largest capacity and self-induction that the equipment thus provided, 12.5 amperes at 100,000 volts and 85,000 cycles per second are produced in the oscillating circuit. Correspondingly when the capacity is reduced to the lowest practicable limit, viz., that of the voltmeter condenser and the self-induction is limited to that of the pair of small innermost helices, 8.1 amperes and 13,000 volts at 612,500 cycles are produced.

The carborundum protective resistance in series with the sphere-gap voltmeter could not be used at frequencies much above 123,000 cycles. This is due to the magnitude of the charging currents inevitably taken by the spheres and their connections, which cause excessive losses in resistances proportioned so as to limit properly the 1200-volt direct power-current that follows a discharge across the gap. At higher frequencies a fine-wire fuse, guarded to prevent corona, was used to limit the injury produced by the power currents. The capacity of the fuse must necessarily be large enough to carry the charging currents taken by the spheres and their connections. On

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this account such fuse capacity cannot be made small enough entirely to prevent injury to the spheres. To overcome this difficulty in the later stages of the work, when frequencies higher than 123,000 cycles were used, the Fortescue-Chubb-Farnsworth mounting for the spheres had to be slightly modified. The brass rods supporting the seven-in. (17.7-cm.) spheres were terminated in shallow cups with inside surfaces fitting them. The spheres were then mounted upon these cups, being held in place by thin sheet brass halters and rubber bands. These changes in the sphere gap standard do not appear to be of material consequence as affecting its integrity for the present class of measurements, while they permit the spheres to be rotated when their adjacent surfaces have been injured so as to bring into use new and uninjured surfaces. By this means the reliable useful life of the spheres is prolonged to such an extent that their renewal cost becomes nominal.

## High-Frequency Meter

In the present undertaking a reliable frequency or wave meter is of prime importance. The frequency meter employed was made by connecting an inductance standard in series with a variable condenser of reliable make and of a type commonly employed in radio-work. Three entirely independent methods were employed for standardizing this meter.

1. *By Calculation*: In this method the value of the inductance was calculated. The conductor used in its construction was enamel-insulated litzen draht, silk jacketed. When constructed, the dimensions were obtained with some care. Perry's formula[1] and Doggett's method[2] were used to calculate independent values of the inductance. The results obtained were 879.0 and 882.5 microhenrys. The variable condenser was compared with a standardized condenser of the Federal Telegraph Company. It was also compared with an air-core standard formed of two concentric brass tubes. The scale of the condenser was found to be true and linear. Its total capacity at the 180-deg. setting compared with the Federal standard was found to be 0.00405 microfarad and with the brass tube standard 0.00407 microfarad.

1. Perry's Approximate Self-Inductance Formula. *Bulletin*, Bureau of Standards. Vol. 8, No. 1, p. 136. Jan. 1, 1912.

2. Leonard A. Doggett. The Inductance of Air-Cored Solenoids. *Electrical World*, Vol. 63, p. 259, January 31, 1914.

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II. *By Direct Measurement, as follows*: At a definite setting of the wave meter the current through and the voltage across the terminals of the meter condenser were read. A one-ampere Hartmann and Braun hot-band ammeter was used for the current and a Kelvin multicellular electrostatic voltmeter for the voltage. The latter instrument is essentially an air-core condenser. Its capacity could be determined conveniently and accurately by noting the change in the frequency meter reading that was caused by its presence. An exact correction on its account could therefore be made. The frequency was then calculated from the simple and well known relation of voltage current and capacity. This value was found to be 123,000 cycles to check with 122,500 cycles obtained by method I.

III. The wave meter was then taken to the factory of the Federal Telegraph Company in Palo Alto. There, through the courtesy of Mr. Ralph Beal, it was compared with the wave meter that had been standardized by the Bureau of Standards. The two wave meters were found to be in close agreement, differing only by $\frac{1}{4}$ per cent.

For higher frequencies the wave meter was recalibrated by method II to eliminate errors that appear due to the internal capacity of the wave meter inductance.

## High-Frequency High-Voltage Meters

The high voltages generated in the main condenser, $C$, Fig. 1, of the oscillating circuit, contain pure sine waves of a single frequency only. The rough pulsating voltages of the generator arc are completely absorbed by the main inductances, $L_1 L_2$, in the oscillating circuit. A reliable voltage meter was, therefore, made out of a suitable condenser of known capacity connected in series with a hot-band ammeter that is free of frequency effects.

For balancing purposes and to employ convenient dimensions in other respects, it was found best in the present work to make up and use two of these condenser-type voltage meters. The manner of their construction is shown at $V_1 V_2$ in Fig. 1. They were made in principle the same as that used by Chubb and Fortescue in standardizing the Farnsworth-Fortescue sphere gap voltmeter.[3] Each condenser was made concentric and near to these specified dimensions: Outer cylinder: inner diameter 11.0 in. (27.9 cm.) length 72 in. (1.8 m.). Inner cylinder: outer diameter 7.0 in. (17.7 cm.), gross length, not including wood-

3. L. W. Chubb and C. Fortescue, Proc. A.I.E.E., Feb. 1913, p. 627.

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mounted hemispherical tinfoil-covered end caps, 61.0 in. (1.54 m.) Two central sections effective for use; one, length 12 in. (30.4 cm). the other 24 in. (60.9 cm.); total when connected in multiple 36 in. (91.4 cm.). These cylinders were constructed of 23-mil galvanized iron. The inner cylinders were carried on a nine ft. (2.7-m.) length of common 1 3/4-in.(3.44-cm.) galvanized iron pipe. The outer cylinders were mounted one over the other, in an A-frame of wood, insulated on porcelain cleats from the cement floor against the small differential voltage; the inner cylinders were supported in position by sash cords. This support was made adjustable for centering by wedges. Errors due to eccentricity were measured and found to be negligible by noting changes in charging currents indicated by a synchronous commutator and portable direct-current galvanometer. The high-frequency, high voltages were applied to the inner cylinders by connecting to the pipe ends remote from the arc-generator. On the pipe ends facing the main inductances and the arc-generator, metal guard hoods were attached, $A_1A_2$. In them, five-ampere or one-ampere, hot-band ammeters were mounted and connected in series with the pipe and the central insulated condenser sections, so as to measure the charging current taken by such sections. The fronts of the hoods were made hemispherical of fine wire mesh to admit light. Through these, openings were cut to facilitate reading the ammeters from a distance by means of telescopes. An observer going near enough to read these instruments with the unaided eye would greatly disturb the balance of the oscillating system, cutting down the high frequency voltage sometimes by as much as 50 per cent, through the increased duty demanded of the arc when circulating current in an unbalanced circuit. Since the capacity values of the used sections of these condensers are made definite in terms of their linear dimensions by means of the guard ends, calculation was relied upon entirely to determine such values. In the upper cylinder the total capacity of the 36 in. (91.4 cm.) of used section was found to be 0.0001140 microfarads, and correspondingly, for the lower cylinder 0.0001145 microfarads. In obtaining the results herein reported, a five-ampere ammeter was used in series with the 0.0001145 microfarads in the lower cylinder and a one-ampere ammeter in series with one third of the aggregate 0.0001140 microfarads available in the upper cylinder.

For safety, the outer upper and lower cylinders, which operate nearly at ground potential, are connected to the electrodes of a

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horn-gap bridged with a long fine-wire fuse. Occasionally when the arc was about to break an unbalancing surge would produce an extra high voltage that would discharge across the double two-in. (50.8 mm.) gaps between the voltmeter cylinders. If such discharge should strike the section of the inner cylinder that is connected through an ammeter it might be burned out before the fuse would interrupt the resulting short circuit. To prevent this, aluminum rings made from 1/4-in. (6.3-mm.) rod were fitted over the extreme ends of the inner cylinders. The discharges then took place from these rings, removing the danger from injury to the hot-band ammeters by short circuits. See Fig. 1. To lessen the spread of the electrical field set up from the hoods covering the ammeters, a sheet metal screen was mounted near them. This screen, the outer cylinders and the large hood over the cylinders, forming the main oscillating-circuit condenser, were all connected and operated near zero potential.

Stability in the production of high voltages by resonance from an arc-generator as a source, depends upon the constants of the oscillating circuit. These must be so established and related that oscillations can be set up at a single frequency only. In the equipment herein specified this condition could not be fully realized without encountering too much cost. The use of a single main condenser in series with two magnetically coupled inductances in the oscillating circuit fixed the frequency and gave ample stability. When the two concentric voltmeter condensers were added to the main condenser, it was found that the voltage duty put upon the arc-generator was somewhat increased. The oscillating freedom of the circuit was correspondingly impaired. This was no cause of difficulty in measuring voltages up to 50,000. Above 50,000 volts one or the other of the concentric voltmeter condensers was apt to flash over due to a tendency of the complex circuit to start local damped oscillations at much higher frequencies. The condenser voltmeter could not be used, therefore, to measure voltages much beyond 50,000.

## The Sphere-Gap Standard

Electrolytic copper spheres were used and mounted on the ends of brass tubes in treated wood frames with proportional dimensions exactly as specified by Farnsworth and Fortescue.[4] Satisfactory spheres may be obtained at small cost by selecting

4. S. W. Farnsworth & C. L. Fortescue, Proc. A.I.E.E., Feb. 1913, p. 299.

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them for regularity of surface curvature from the commercial float ball product. Well-impregnated paraffined oak was used for the cross pieces through which the brass tubes pass to support the spheres. The rest of the frame was made of Oregon pine. Under the stress of high-frequency high voltage all dielectrics accept large charging currents. Ample and close electrode contact entirely free of all corona, must be made to lead these charging currents into the stressed dielectric so as to prevent burning or other injury. Accordingly the holes through the oak cross pieces were bushed with brass sleeves cemented to the wood by paraffin treatment. Without this precaution the frame will promptly be set afire. For balancing purpose we had to set this sphere gap standard rather high off the floor. For reasons given above it could not be operated with one terminal grounded as recommended by Fortescue, Chubb and Farnsworth. We also used a long wooden lever and screw jack to facilitate accurate gap settings. Gap lengths were determined by means of calipers and micrometer screw or steel scale.

Finally reference is made to the three illustrations Figs. 2, 3 and 4, which give to the eye much additional information relating to the construction and arrangement of the equipment as employed and above described.

## Features of Unsteadiness in the High-Frequency High Voltages Generated in the Apparatus as Used and Described Above

The character of the high-frequency voltages was examined with the aid of the cathode ray cyclograph. The ray was given an alternating deflection in one plane magnetically, and in a quadrature plane, electrostatically. The magnet deflections were produced by the oscillating currents. Limitations in the behavior of the cathode ray tube made it necessary to use an air-core transformer in series with the oscillating circuit. The secondary of this transformer was short circuited through the current coils of the cyclograph and grounded. Thus the cathode ray was not subjected to the potential disturbances that occur when the deflecting coils are directly connected in series with the oscillating circuit adjacent to an ungrounded electrode of the generator-arc.

The ray was deflected electrostatically by "quadrants" charged with the potentials of spherical electrodes that were

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dipped into the powerful electrostatic field of the main condenser. The two alternating motions thus imparted to the ray being in quadrature, it was made to trace an ellipse on the observing screen of the tube. One could then note the characteristic manner in which the magnitude of the high frequency voltage varied. The lowest current that could ordinarily be maintained in the oscillating circuit at 123,000 cycles was 3.0 and the highest 12.5 amperes, corresponding to 12.0 and 50.0 kilovolts respectively. The cyclograph indicated unsteady voltage fluctuations amounting to a maximum of 15 per cent, approximately, at 3.0 oscillating amperes. As the oscillating amperes increased the instantaneous voltage became quite steady, fluctuating less than 5 per cent, maximum. As the current approached 6.0 amperes producing 24.0 kilovolts, the voltage became quite unsteady. It was always difficult to operate the arc-generator at 6.5 amperes. At such current the hot-band ammeter reading fluctuates and the cyclograph indicates violent fluctuations in the oscillating current and voltage. Persistence of vision frequently caused two concentric cyclograms to appear upon the screen, one corresponding to a current of about six, and the other, seven amperes. Because of this characteristic of the arc no attempt at any time was made to determine sphere-gap discharge voltages at or near 6.5 amperes corresponding to 26.0 kilovolts. At seven amperes and upward to 12.5 amperes, the cyclograph again indicated steady instantaneous oscillating voltage, whenever the hot-band ammeter in the oscillating circuit produces steady readings.

In making sphere-gap voltage discharge observations the arc-generator was operated and controlled so as to establish a definite high-frequency current in the oscillating circuit. While the sphere gap was shortened slowly to produce the discharge, the ammeters in the main oscillating and voltmeter condenser circuits were read. A set of observations was considered good only when the ammeters gave steady indications. In general, however, under the most steady operating conditions there are some slight and rather rapid fluctuations in the values of the current and, therefore, voltage. The ammeters can only indicate the effective average of such currents and voltages. On the other hand, it is the effective maximums of the slightly fluctuating voltages that actually produce most of the discharges between the spheres. In this manner variable errors are produced in the results, and some strategy is necessary to accomplish

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their approximate elimination. These errors always operate to produce apparent voltage values that are smaller than their corresponding true values. For obvious reasons the sphere gap can be shortened only at a slow rate. If it could be shortened at a very high rate and the process stopped at the exact length through which the discharge occurred, all settings would have nearly equal weight in determining the final true result. Under the actual working conditions in this equipment, it is hardly likely that the observed voltages are ever above the true voltages that actually produce the discharge between the spheres. Oc-

TABLE I
TYPICAL OBSERVATIONS

| | Temp. 18 deg. cent. (approx.) | | | Barometer 30 in. (approx). | | |
|---|---|---|---|---|---|---|
| Date | H-B 5-amp. No. 439188 constant multiplier 1.03 0.0001145 m. f. | H-B 1-amp. No. 429926 constant multiplier 1.02 0.0000380 m. f. | H-B 30-amp No. 439113 in main oscillating circuit | Degrees variable capacity (frequency meter180)°= 0.00406 mf. Inductance = 881. micro-henrys | 7-in. sphere gaps, inches | Arc voltages gage |
| 1914 | | | | | | |
| Feb. 5 | 1.45 | 0.460 | 7.90 | 84.60 | 0.695 | |
| " 5 | —— | —— | 8.00 | " | 0. 93 | —— |
| " 14 | 1.43 | 0.456 | 8.00 | " | —— | —— |
| " 14 | 1.50 | 0.474 | 8.45 | " | —— | —— |
| " 14 | —— | —— | 9.00 | 84.5 | 0.801 | 48. |
| " 14 | —— | — — | 9.10 | " | 0.821 | 42. |
| " 14 | —— | —— | 9.10 | " | 0.820 | 43. |
| " 19 | 1.95 | 0.630 | 11.20 | 85.3 | 1.04 | 40. |
| " 19 | 2.08 | 0.670 | 11.80 | " | 1.03 | —— |
| " 19 | 2.13 | 0.690 | 12.20 | 84.5 | 1.06 | 42. |

casionally, however, the readings of the instruments must correspond much more nearly to the voltages applied to the spheres at the instant they discharge. *The corresponding results will be least in error and must have most weight in determining the final and true relation between voltages and spark gap lengths.*

## DISCUSSION OF RESULTS

Some of the original observations are given in Table I. The constants of the measuring instruments are also given, so that one may compute the corresponding results for himself. The results obtained are given in Tables II and III and charted

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TABLE II
RESULTS

| Frequency | 7-inch sphere gaps; inches | Kilovolts by instruments |
|---|---|---|
| 123,000 | 0.427 | 20.2 |
| " | 0.429 | 19.8 |
| " | 0.452 | 20.0 |
| " | 0.540 | 24.7 |
| " | 0.673 | 33.0 |
| " | 0.693 | 33.0 |
| " | 0.695 | 32.7 |
| " | 0.704 | 33.0 |
| " | 0.738 | 32.7 |
| " | 0.784 | 35.7 |
| " | 0.800 | 35.8 |
| " | 0.811 | 36.6 |
| " | 0.820 | 37.0 |
| " | 0.821 | 37.0 |
| " | 0.863 | 40.7 |
| " | 0.878 | 40.7 |
| " | 1.03 | 47.5 |
| " | 1.04 | 44.7 |
| " | 1.06 | 48.8 |
| " | 1.06 | 48.0 |
| " | 1.09 | 49.8 |
| " | 1.09 | 49.4 |
| " | 1.10 | 48.5 |
| " | 1.10 | 50.4 |
| " | 1.16 | 51.8 |

TABLE III
RESULTS

| Frequency | 7-inch sphere gaps; inches | Kilovolts, by instruments |
|---|---|---|
| 255,000 | 0.261 | 13 500 |
| " | 0.253 | 13 300 |
| " | 0.248 | 13 250 |
| | | |
| " | 0.371 | 19 060 |
| " | 0.378 | 18 460 |
| " | 0.382 | 18 400 |
| " | 0.337 | 17 670 |
| " | 0.404 | 20 770 |
| | | |
| " | 0.898 | 43 300 |
| " | 0.817 | 42 600 |
| " | 0.886 | 42 200 |
| " | 0.920 | 42 300 |
| " | 0.901 | 41 900 |
| " | 0.931 | 43 700 |
| " | 0.934 | 44 200 |
| | | |
| 612,500 | 0.320 | 14 950 |
| " | 0.263 | 12 300 |
| " | 0.285 | 13 200 |
| " | 0.242 | 12 480 |
| " | 0.250 | 12 200 |

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in Fig. 5. It is noted that the 123,000-cycle values, when the fluctuating character of the source is ignored, locate a right line relation for the sphere gaps and discharge voltages; and that such line when extended passes through the origin. See curve I, Fig. 5. All values determined at 123,000, 255,000 and 612,500 cycles locate curve II, Fig. 5, when errors due to the fluctuation of the source are largely eliminated.

Curve III, Fig. 5, was drawn for comparison; it was located ·

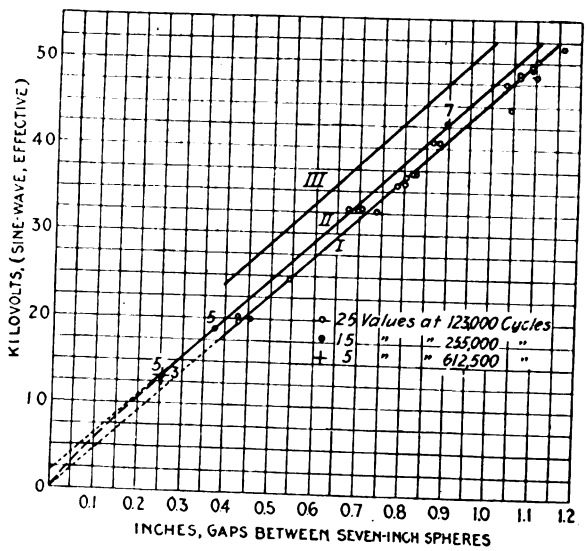


FIG. 5

I. Seven-inch sphere-gap discharge voltage at 123,000 cycles, fluctuations of source ignored. 25 determinations.

II. Ditto. 25 determinations at 123,000 cycles, 15 determinations at 255,000 cycles and 5 determinations at 612,500 cycles. Fluctuations of source eliminated by giving maximum weight to minimum gaps for corresponding voltages.

III. 25-, 37.5- and 50-centimeter sphere-gap discharge voltages at 25 cycles determined by Chubb and Fortescue, Proc. A. I. E. E., Feb. 1913, pp. 635-6.

with the observations made by Chubb and Fortescue for 25 cycles discharge voltages and 25, 37.5- and 50-cm. sphere gaps. These observations are recorded on pp. 635-6 of the February, 1913, PROCEEDINGS A. I. E. E. The high-frequency voltages are almost uniformly 4.5 kilovolts below the 25-cycle voltages. No cause for this difference could be found in our methods of measurements. We believe that both curves have been correctly located.

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## Conclusions

1. The seven-in. (17.7-cm.) sphere-gap discharge voltages at frequencies ranging from 123,000 to 255,000 cycles per second are given by the expression

$$e = 45.5\, l + 2$$

for the gap range of 0.4 to 1.1 in. (1 to 25.6 mm.), wherein the value of $e$ is in kilovolts, r.m.s., and the value of the sphere gap, $l$, is in inches at ordinary atmospheric conditions: Temp. 18 deg. cent.; Barom. 30 in.

2. Correspondingly at 612,500 cycles per second, 13.06 kilovolts, r.m.s., discharge through a seven-in. sphere-gap length of 0.252 inch.

3. Needle gaps are not practicable for the determination of high-frequency high voltages. The points are promptly melted and burned. Only gaps between blunt points can be employed. For these, No. 14 B. & S. gage, square-ended copper wires were used. The measured voltages were found to be about one-half of the corresponding voltages at 60 cycles.

## Acknowledgements

The writers could not have undertaken the present work without special equipment, provided as follows:

Mr. Cyril F. Elwell presented the Department of Electrical Engineering, Leland Stanford Junior University, with a five-kilowatt Poulsen arc oscillating-current generator. Later on the Federal Telegraph Company generously exchanged this generator for a powerful 12-kw. Poulsen-Federal arc-generator, together with a variable condenser and special minor supplies such as litzen draht, carbons and bushings. Invaluable advice and suggestions were rendered in the earlier stages of the work by Mr. Elwell and Mr. Leonard F. Fuller.

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*To be presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 25, 1914, under the auspices of the Committee on Prime Movers.*

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(*Subject to final revision for the Transactions.*)

# PRESENT STATUS OF PRIME MOVERS

BY H. G. STOTT, R. J. S. PIGOTT AND W. S. GORSUCH

ABSTRACT OF PAPER

The paper brings out in a concise form the present status of heat engines and hydraulic turbines in commercial use today for the conversion of the energy found in fuel and water into mechanical power for the production of electric energy.

The various types are compared as to relative importance, capacity, efficiency, weight, cost and economy, which are illustrated by curves plotted on kilowatt basis.

(a) Reciprocating Steam Engine.
(b) Steam Turbine
(c) Gas Engine
(d) Oil Engine
(e) Hydraulic Turbine
(f) Finance and Economics

Curves are plotted showing the investment and fuel costs of the different heat engine units, on the basis of percentage of normal full load rating of machines.

THE Committee on Prime Movers has selected the following subdivisions of its subject, in order to cover the most important recent developments in the field of prime movers:

1. Reciprocating steam engine
2. Steam turbine
3. Gas engine
4. Oil engine
5. Hydraulic turbine
6. Finance and economics.

In order to show the present status of the art in a graphic manner, practically all of the data obtained have been plotted in curves which appear in the appropriate place in the text.

## RECIPROCATING ENGINE

The reciprocating steam engine has, during the past five years, become practically obsolete for use in modern power stations. In the large new central station this engine is not even considered; but in small isolated stations it is still used to a considerable extent, especially where heating service is also handled. In small sizes, the engine still has some advantage in economy



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over the small turbine, but the margin is getting continually smaller; some of the latest geared units being almost on equal terms. The non-condensing and bleeder turbines have offered a satisfactory substitute for the engine on heating service: the continuance of the engine in use is therefore chiefly due to the apparent inability of purchasers for isolated plants to realize that economy of steam is only one of the items constituting cost of power. The superior reliability, low maintenance, sustained original economy, and low attendance cost of the turbine generally overbalance the rather doubtful advantage in original economy of the small reciprocating engine.

## Steam Turbine

The steam turbine is now at the head of the list of prime movers. The items of comparison with other prime movers are:

(a) Capacity
(b) Efficiency
(c) Weight
(d) Price.

*Capacity and Efficiency.* Usually the figure quoted as the measure of efficiency is the water rate or steam consumption per kilowatt hour. Hardly any measure can be selected which is less satisfactory, since, unless the steam and vacuum conditions are stated, the water rate means nothing. Two turbines of exactly equal merits may be quoted as having very different water rates if one is operated on superheated steam with high vacuum, and the other wet steam and lower vacuum. To fix the merits of the design, a knowledge of the efficiency ratio (Rankine cycle) is necessary; and to fix the thermal efficiency, a knowledge of the steam conditions is needed—in other words, the heat drop available.

The water rate of a perfect Rankine-cycle engine is given as 3415 divided by the available adiabatic heat drop between initial and final conditions of the steam. Table I gives a few values for the commoner conditions in use. The efficiency ratio is equal to the Rankine-cycle water rate divided by the actual water rate of the turbine. The thermal efficiency and the water rate are both dependent upon the steam conditions, and can never be correctly compared except upon the same basis of pressure, superheat and vacuum.

The efficiency ratio is a measure of the goodness of the design, influenced somewhat by steam and vacuum conditions. The

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TABLE I

HEAT DROP AND WATER RATES FOR 100 PER CENT RANKINE-CYCLE EFFICIENCY.

| Press. | Dry steam. | | | | | | 100 deg. superheat. | | | | | | 150 deg. superheat. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 28 in. | | 28.5 in. | | 29 in. | | 28 in. | | 28.5 in. | | 29 in. | | 28 in. | | 28.5 in. | | 29 in. | |
| | H.D. | W.R. | H.D. | W.R. | H.D. | W.R. | H.D. | W.R. | H.D. | W.R. | H.D. | W.R. | H.D. | W.R. | H.D. | W.R. | H.D. | W.R. |
| lb. per sq. in. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. | B.t.u. per lb. | lb. per kw. |
| 165 | 324 | 10.52 | 338 | 10.09 | 355 | 9.61 | 345 | 9.89 | 360 | 9.47 | 378 | 9.03 | 353 | 9.66 | 368 | 9.27 | 387 | 8.82 |
| 190 | 331 | 10.30 | 348 | 9.80 | 364 | 9.37 | 356 | 9.58 | 369 | 9.25 | 387 | 8.82 | 365 | 9.35 | 379 | 9.00 | 398 | 8.57 |
| 215 | 341 | 10.00 | 354 | 9.63 | 371 | 9.19 | 363 | 9.40 | 376 | 9.08 | 394 | 8.66 | 373 | 9.14 | 387 | 8.81 | 406 | 8.41 |
| 240 | 347 | 9.83 | 361 | 9.45 | 378 | 9.02 | 371 | 9.19 | 385 | 8.86 | 403 | 8.46 | 380 | 8.98 | 396 | 8.61 | 413 | 8.24 |
| kg. per sq. cm. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. | cal. per kg. | kg. per kw. |
| 11.59 | 180.0 | 4.78 | 187.8 | 4.58 | 197.1 | 4.36 | 191.5 | 4.48 | 199.9 | 4.30 | 209.8 | 4.09 | 196.0 | 4.38 | 204.5 | 4.21 | 214.8 | 4.00 |
| 13.36 | 183.8 | 4.67 | 193.1 | 4.45 | 202.1 | 4.25 | 197.8 | 4.34 | 204.8 | 4.19 | 214.5 | 4.01 | 202.5 | 4.24 | 210.5 | 4.08 | 221.0 | 3.89 |
| 15.10 | 189.2 | 4.53 | 196.3 | 4.38 | 206.0 | 4.17 | 201.5 | 4.27 | 208.8 | 4.12 | 218.5 | 3.93 | 207.2 | 4.14 | 215.0 | 4.00 | 225.2 | 3.82 |
| 16.87 | 193.7 | 4.43 | 200.5 | 4.29 | 209.8 | 4.10 | 206.0 | 4.17 | 213.5 | 4.03 | 224.0 | 3.84 | 211.6 | 4.07 | 219.8 | 3.91 | 229.5 | 3.75 |

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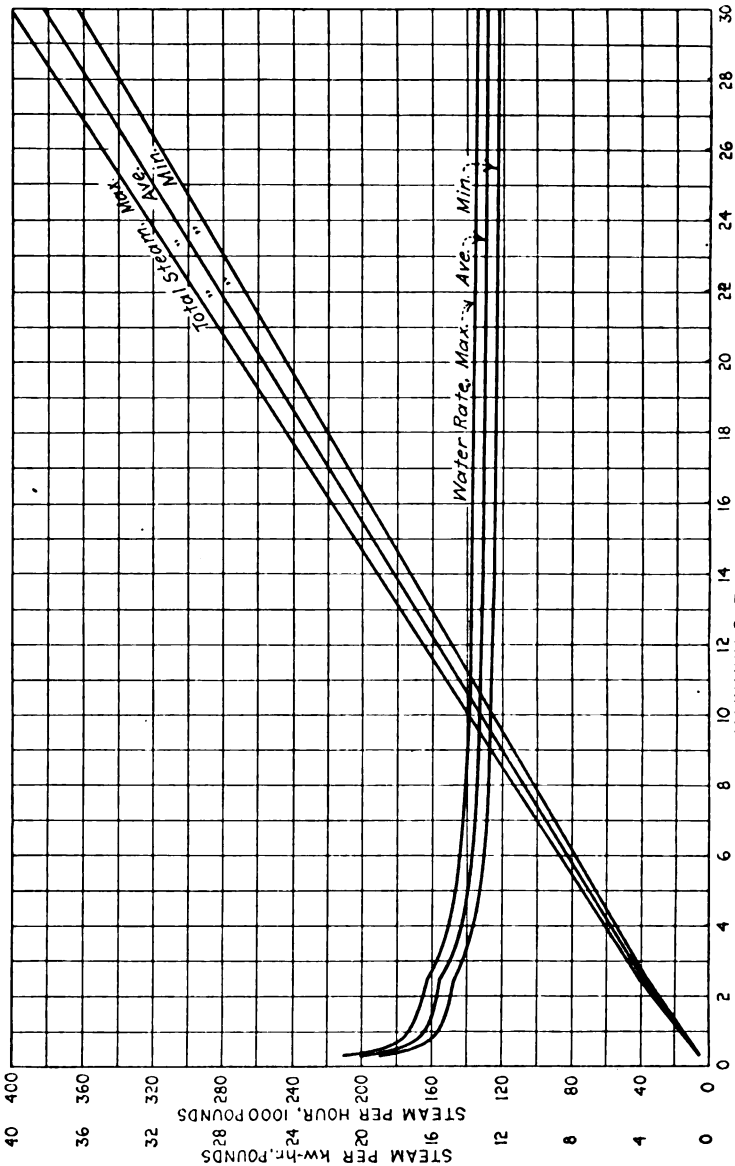


FIG. 1—STEAM TURBINES—TOTAL STEAM VS. CAPACITY—STEAM PER KW-HR. VS. CAPACITY.
60 cycles, max. 24-hr. rating, 50 deg. cent. rise; power factor 80 per cent, pressure 175 lb., superheat 100 deg. fahr; vacuum 28.5 in.

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efficiency ratios of modern turbines differ much less from each other than the variation of water rates would lead one to suppose.

The efficiency ratio increases (a) with size, (b) with superheat, (c) with reduction of vacuum down to about 26 in. (66 cm.), (d) with reduction of pressure. Speed also effects efficiency ratio, either to increase or decrease it, depending upon the design and conditions. Thermal efficiency increases (e) with pressure, (f) with superheat, (g) with vacuum. It is evident that some of these conditions at least are incompatible with each other, and that the turbine having the best water rate may not have the highest efficiency ratio.

Fig. 1 shows water rates which may be obtained for various sizes of machines. For the standard conditions of 175 lb. (79.3 kg.) gage, 100 deg., superheat, 28½ in. (72.4 cm.) vacuum, the average value is that which will ordinarily be obtained for standard designs; but better or poorer rates may be obtained under special conditions, either of design for high efficiency, which increases cost, or of cheap construction, which usually means poor water rate.

Fig. 2 shows the Rankine-cycle efficiency ratios under the same conditions. For the same sizes of machine, 25-cycle generators will have the same water rate and efficiency ratios, as the variation in speed can be readily cared for without sacrifice of efficiency. The corrections for other steam and vacuum conditions must be applied to get the proper water rates,—these differing somewhat for different types. The usual superheat correction is one per cent improvement in water rate for each 10 deg. superheat between saturation and 100 deg.; one per cent for each 12½ deg. superheat between 100 and 200 deg. superheat. The vacuum correction varies considerably with different machines, and amounts to about 5 per cent improvement between 27 and 28 in. (68.5 and 71 cm.); 6 per cent between 28 and 29 in. (71 and 73.9 cm.) A better method is to use the total heat drop available in each case as a ratio applied to the water rate. An important feature influencing cost is the matching of generator and turbine. In many cases the turbine has its best water rate at the maximum 24-hour rating of the generator. For many purposes this is undesirable. The best water rate should occur at from 75 to 85 per cent of the maximum 24-hour rating of the generator; in other words, the turbine should be smaller than the generator.

The overload devices (extra nozzles in the case of impulse

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turbines and by-passing in the reaction turbines) can be readily designed to take care of the loads up to 50 per cent in excess of the best water rate load in the turbine. The best water rate

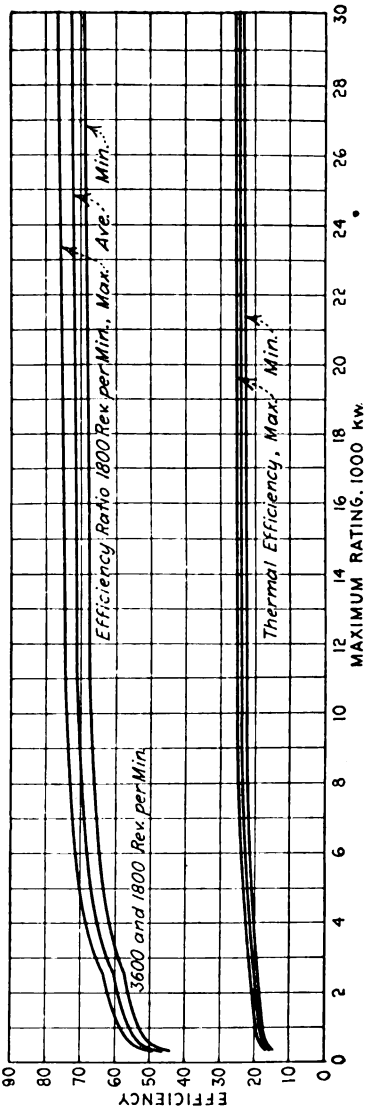
Efficiency Ratio 1800 Rev. per Min., Max. Ave. Min.
3600 and 1800 Rev. per Min.
Thermal Efficiency, Max. Min.
EFFICIENCY
MAXIMUM RATING, 1000 KW.
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
90 80 70 60 50 40 30 20 10 0

FIG. 2—STEAM TURBINES—RANKINE-CYCLE EFFICIENCY RATIO AND THERMAL EFFICIENCY VS. CAPACITY
Max. 24 hr. rating, 50 deg. cent. rise; pressure 175 lb.; superheat 100 deg. fahr; vacuum 28.5 in.

reached by the turbine occurs just before these overload devices operate; and it is for the steam flow at these loads that the turbine proportions are designed. When the effect of auxi-

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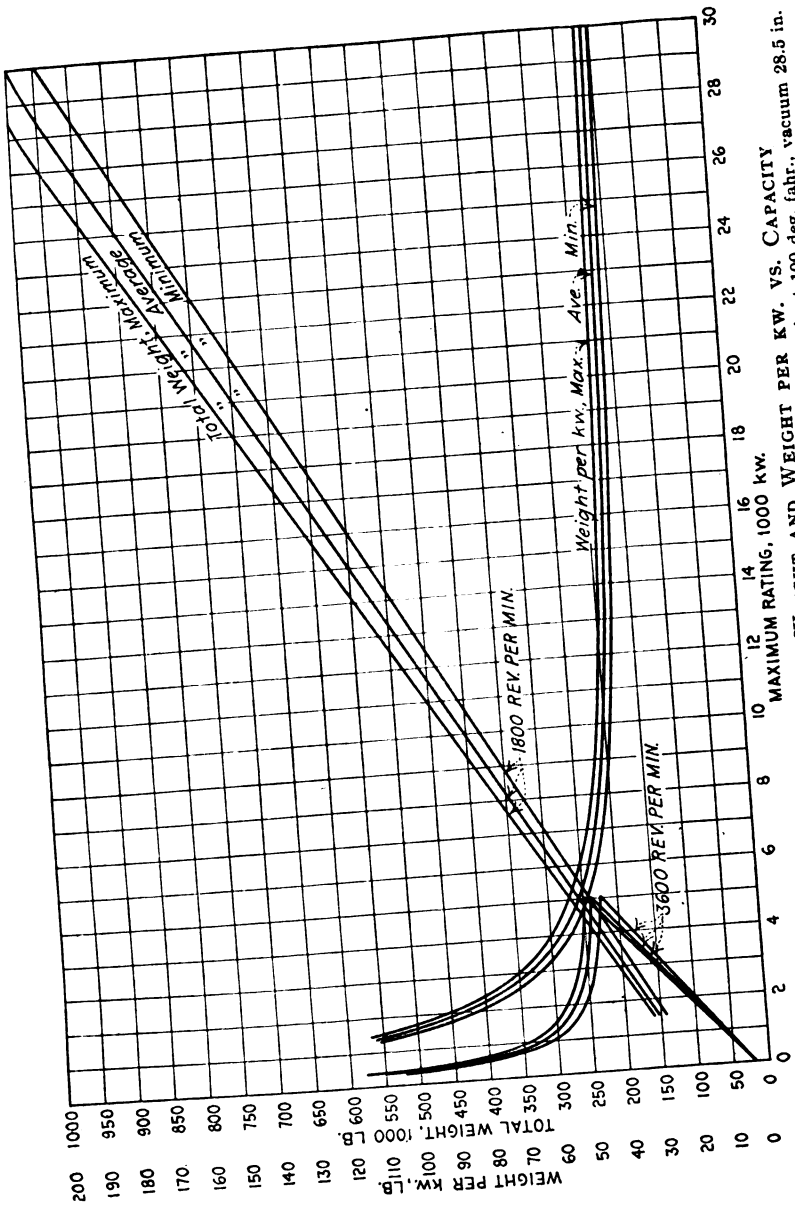


FIG. 3—STEAM TURBINES—TOTAL WEIGHT AND WEIGHT PER KW. VS. CAPACITY

60 cycles, max. 24 hr. rating, 50 deg. cent. rise; power actor 80 per cent., pressure 175 lb.; superheat 100 deg. fahr., vacuum 28.5 in.

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liary steam consumption on the steam demand of the engine room is considered, it is evident that the under-sizing of the turbine to a small degree is desirable.

*Weight.* The weight increases with the increase of vacuum, decrease of speed, decrease of initial pressure, and increase of efficiency ratio. The increase of vacuum obviously affects the weight by increasing the size of the exhaust end and the blading. Decrease of speed increases the weight, as it enlarges the dimensions in every direction for a given capacity, and sometimes increases the number of stages for a given efficiency. Increase of efficiency ratio usually implies sharper blade angles, more stages, and larger blading, which obviously increases the weight. Fig. 3 gives the total weight and weight per kilowatt under the standard conditions previously stated.

*Cost.* The turbine design is usually a compromise between cost of manufacture and efficiency. The cost is influenced by steam conditions, speed, and by type, to some extent. Increased thermal efficiency means increased cost, as it means increased blade dimensions, stages, and exhaust openings for higher vacuum, and in some cases altered construction to suit higher superheats.

Fig. 4 is cost per kilowatt and total cost for machines built to the standard conditions previously given, delivered and erected within 600 miles of factory. 25-cycle machines will cost from 15 per cent more, in smaller sizes, to 10 per cent more in the larger sizes. Cost per lb. (Fig. 5) remains about constant for any given capacity, so that this increase in cost for 25-cycle machines is readily explained, as the reduction in speed from 1800 to 1500 and from 3600 to 3000 revolutions raises the weight approximately in inverse proportion to the decrease in speed.

The three items which influence the purchasing of a turbine are price, water rate and time of delivery. The time of delivery cannot be much reduced beyond a certain point. There is, therefore, a very strong tendency to cut the price or the water rate in order to get the business where competition is very keen. As only about one turbine in every 50 sold is ever tested, the opportunity to manipulate the water rate of the turbine downward has often proved a stumbling block to good engineering. The cost to manufacture any of the standard makes is not very different. The prices ordinarily will therefore be about the same. The tendency to cut the water rate below what can

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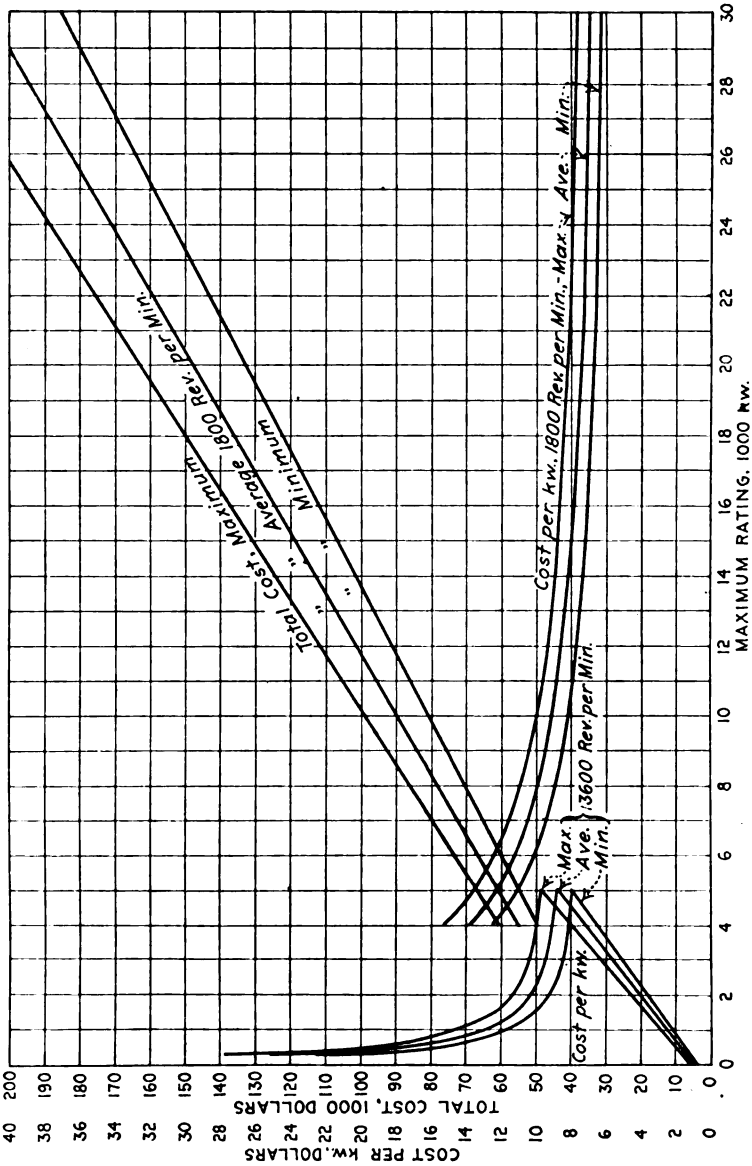
COST PER kw. DOLLARS
TOTAL COST, 1000 DOLLARS
MAXIMUM RATING, 1000 kw.
Total Cost. Maximum 1800 Rev. per Min.
" " Average " " "
" " Minimum " " "
Cost per kw. 1800 Rev. per Min.-Max. Ave. Min.
Cost per kw. 3600 Rev. per Min.-Max. Ave. Min.

FIG. 4—STEAM TURBINES—COST PER KW. VS. CAPACITY.—TOTAL COST VS. CAPACITY

60 cycles, max. 24 hr. rating, 50 deg. cent. rise; power factor 80 per cent.; pressure 175 lb; superheat 100 deg. fahr; vacuum 28.5 in

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actually be obtained can therefore only be checked by the engineer's watchfulness. Comparison with the Rankine efficiency ratio for any size machine is one of the safest means of detecting spurious water rates, since they will give impossible efficiency ratios.

## Gas Engines

The fuel supply for the various classes of this type of prime mover is obtained either by the conversion of coal, coke, lignite, peat, wood, oil or other kindred fuels into a gaseous product in a producer; or from natural resources, or the recovery of waste or by-product gases from blast furnaces and coke ovens. The utilization of natural gas and blast furnace gas has enabled a wide application of the gas engine, amounting to over 75 per cent of the total gas power machinery installed in the United States, the natural gas being in the lead as to aggregate capacity.

The development of large gas engines is largely due to the ideal conditions existing in steel industries where large quantities of blast furnace gas are available, requiring only cleaning to make a perfect fuel for this type of prime mover. Blast-furnace-gas power plants have been especially striking owing to the magnitude of the engine, which has now reached a capacity of 6000 brake horse power for a single unit of the twin tandem type.

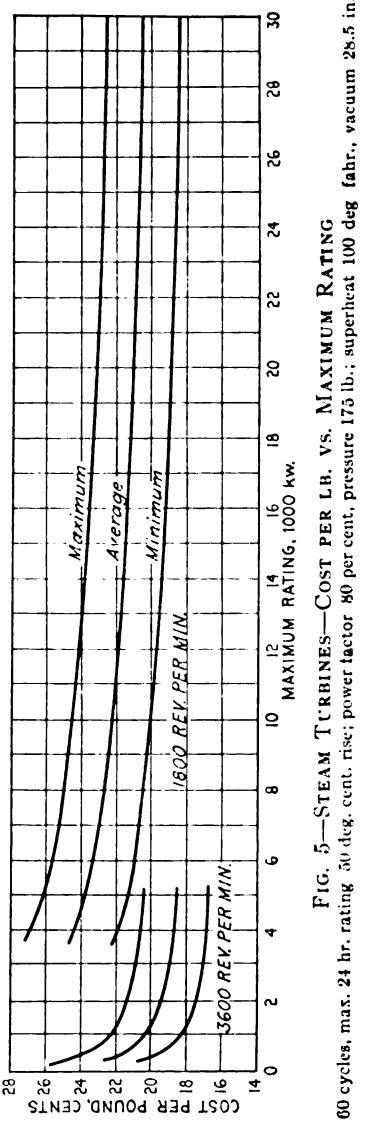


FIG. 5—STEAM TURBINES—COST PER LB. VS. MAXIMUM RATING
60 cycles, max. 24 hr. rating 50 deg. cent. rise; power factor 80 per cent, pressure 175 lb.; superheat 100 deg fahr., vacuum 28.5 in.

The main improvements in gas engines have been in the re-

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inforcement of cylinder castings, simplicity of the cylinder, piston and rod construction, more efficient packing, adoption of the throttling governors, etc.

The rapid introduction of the gas-producer in the manufacture of gas from cheap grades of coal has given special impetus to the producer gas engine. Many of the low grades of fuel which are not fit for use under the steam boiler have been used with reasonable success in the producer.

There is now a growing demand for gas engines to operate with coke oven gas, and probably interesting developments may be expected along this line within the next few years.

With the universal tendency toward high-speed rotative machinery, engineers engaged in the development of internal combustion engines have recently shown renewed activity in substituting rotary for reciprocating motion. While much valuable information has been obtained, yet the practical difficulties have not been surmounted and the gas turbine has not reached a commercial stage. However, if the gas turbine does come, it will probably revolutionize power production in large steel centers and wherever natural fuel oils abound in this country.

*Capacity.* There are two general types of gas engines known as the two-cycle and four-cycle, or two-stroke and four-stroke, built with single- or double-acting cylinders, either vertical or horizontal, the usual form in sizes above 200 brake horse power consisting of two double-acting cylinders set tandem. By combining two such units we have the twin tandem type that is built in sizes as large as 6000 brake horse power. The four-cycle engine is the type that is almost always used in units of any appreciable size, and especially the double-acting four-cycle type with two cylinders arranged in tandem, which was brought to a commercial state about eleven years ago.

Steam turbine and engine ratings are usually such that they are worked under their most economical load at the rating of the electrical generator. With gas engines, on the other hand, the efficiency increases with the load beyond the capacity of the engine (see efficiency curve, Fig. 6), and for this reason the rating of the engine is generally made as nearly as possible to its maximum capacity, allowing from 10 to 20 per cent for overload.

The gas engine does not possess inherent capacity for overloads in the same sense in which the steam turbine and engine do, hence whatever overload it has, is allowed by the manu-

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facturer. The maximum capacity of a gas engine is evidently reached when the cylinder has taken a full charge of mixture of the highest heat value and density, that is, containing the maximum B.t.u.'s (large calories) per cu. ft. (0.028 cu. m.). This being the case, it is evident that gas engines must accommodate themselves to variations in the quality of the gas. Assuming for illustration, that a 10 per cent overload is sufficient, an engine of 550 horse power maximum capacity would then be rated at 500 horse power.

The gas engine being fairly limited as to the power which may be produced in a single unit, there has developed on the part of some manufacturers a disposition to increase speeds. While high speeds have been used in steam turbine and engine practise, it should not be taken as a criterion in gas engine work, as the heavy masses involved in the reciprocating parts of the gas engine may become destructive and the result may be higher maintenance cost.

*Efficiency.* One of the characteristics of the gas engine which other heat engines do not possess is that the thermal efficiency remains fairly uniform over all ranges of sizes.

Fig. 6 shows representative curves of thermal efficiency and rate of heat consumption per kilowatt generated for different percentages of normal full-load rating of large four-cycle producer and natural-gas engines, no allowance being made for auxiliaries.

Many figures have been given of the thermal efficiency of the gas engine which vary materially, but we believe that the curve above referred to gives conditions generally met within large gas engines, namely, 25.2 per cent on the basis of brake horse power, or 23.8 per cent on the basis of kilowatt-hours generated at full load rating. All curves of the gas and oil engines have been referred to the basis of kilowatt-hours generated so as to be comparable with the steam turbine and engine.

The range of fuel consumption as guaranteed by American manufacturers for their engines at full load rating with different fuels varies from 9500 to 13,500 B.t.u. per brake hp-hr. (2394 to 3402 large calories) for producer gas, and 8,500 to 15,000 B.t.u. per brake hp-hr. (2142 to 3780 large calories) for natural gas, or reducing to basis of kw-hr., 13,500 to 19,200 B.t.u. per kw-hr. (3402 to 4838 large calories) for producer gas, and 12,200 to 21,400 B.t.u. per kw-hr. (3074 to 5393 large calories) for natural gas. Blast furnace gas runs in the neigh-

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borhood of 10,500 B.t.u. per brake hp-hr. (2648 large calories), or 15,000 B.t.u. per kw-hr. (3780 large calories) generated.

*Weight.* The operation of the gas engine involves high temperatures and pressures suddenly applied to the working parts, consequently this class of prime mover is inherently massive.

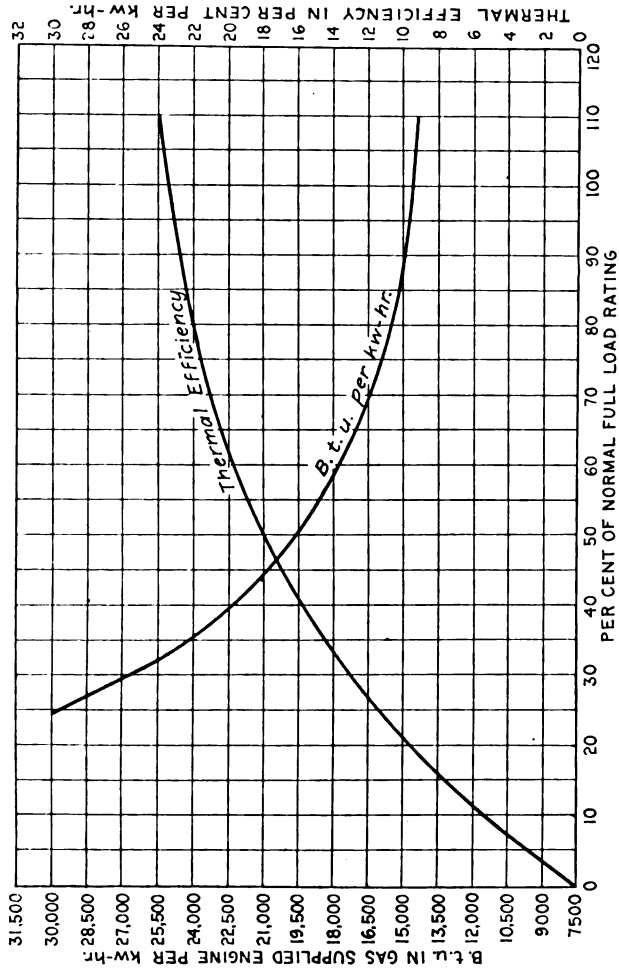


FIG. 6—REPRESENTATIVE CURVES OF LARGE GAS ENGINES USING PRODUCER OR NATURAL GAS AND DIRECTLY CONNECTED TO 60-CYCLE GENERATOR (AUXILIARIES NOT ALLOWED FOR)

The range in weights of the various sizes of horizontal type producer-gas and natural-gas, four-cycle single- and double-acting tandem and twin-tandem gas engines, as manufactured by the largest gas engine companies in this country, are shown in Fig. 7.

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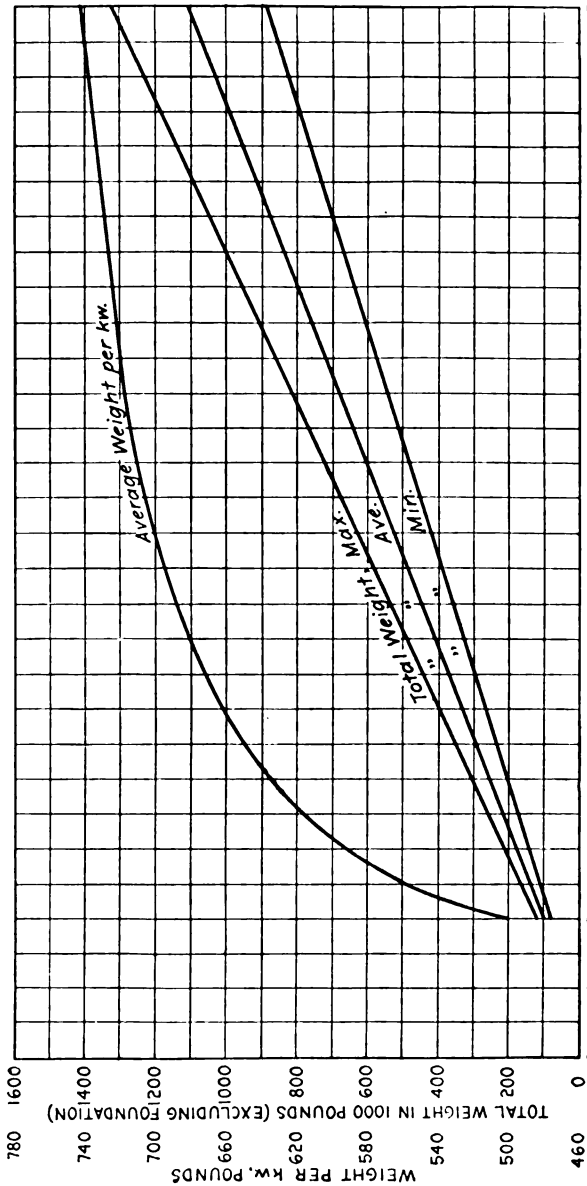


FIG. 7—HORIZONTAL TYPE (AMERICAN MANUFACTURE) PRODUCER GAS AND NATURAL GAS ENGINES, 4-CYCLE, TANDEM AND TWIN TANDEM DIRECTLY CONNECTED TO 60-CYCLE GENERATORS FROM 200 TO 2000 KW. CAPACITY AT 80 PER CENT POWER FACTOR

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These curves are drawn to include all capacities from 200 to 2000 kw., and show that there is a variation of 20 per cent from the average weight. Considering the curve of average weight per kilowatt, one thing is basic, namely, that the big unit weighs more per kilowatt than the small unit. The reason is that as you go up in size and lengthen out the stroke the weight runs up per unit capacity. The weight is governed by many considerations, such as rotative speed, the mean effective pressure on which the builder figures his rating, the nearest size the builder has to fit a given generator, the question of single or double crank, etc.

*Cost.* On account of the heavy parts made necessary by high temperatures and pressures, the gas engine is considerably more expensive to build than steam turbines or steam engines.

In some types of gas engines there is not very much difference between the cost per unit capacity in large and small sizes, whereas with other companies it varies considerably.

Fig. 8 shows the limits of total cost, average cost per kilowatt capacity, and average cost per pound, of the type and size of engine and generator as described in Fig. 7. The price is for engine and generator complete and installed exclusive of foundations within 600 miles of factory. It will be seen that the price varies 18 per cent from the average for the different types.

The cost of the gas engine is influenced by the same conditions that govern the weight, as explained above. The different combinations of stroke and synchronous speed result in varying piston speeds, and for a given power the price will be higher the lower the speed. Many attempts have been made to lower the cost of the gas engine by decreasing its weight without impairing its reliability, and to increase its capacity by increasing the pressure of the charge and simultaneous scavenging of the exhaust gases, but all without definite results.

## Oil Engines

Oil engines have progressed rather slowly in this country, while in Europe the development has been more marked, especially since the expiration of the basic Diesel patents in 1912.

The Diesel engine is essentially a vertical type, but the last two years have witnessed a remarkable development of the horizontal type. While tests show that the fuel consumption is slightly higher than with the vertical type, nevertheless on account of the greater simplicity and better accessibility and

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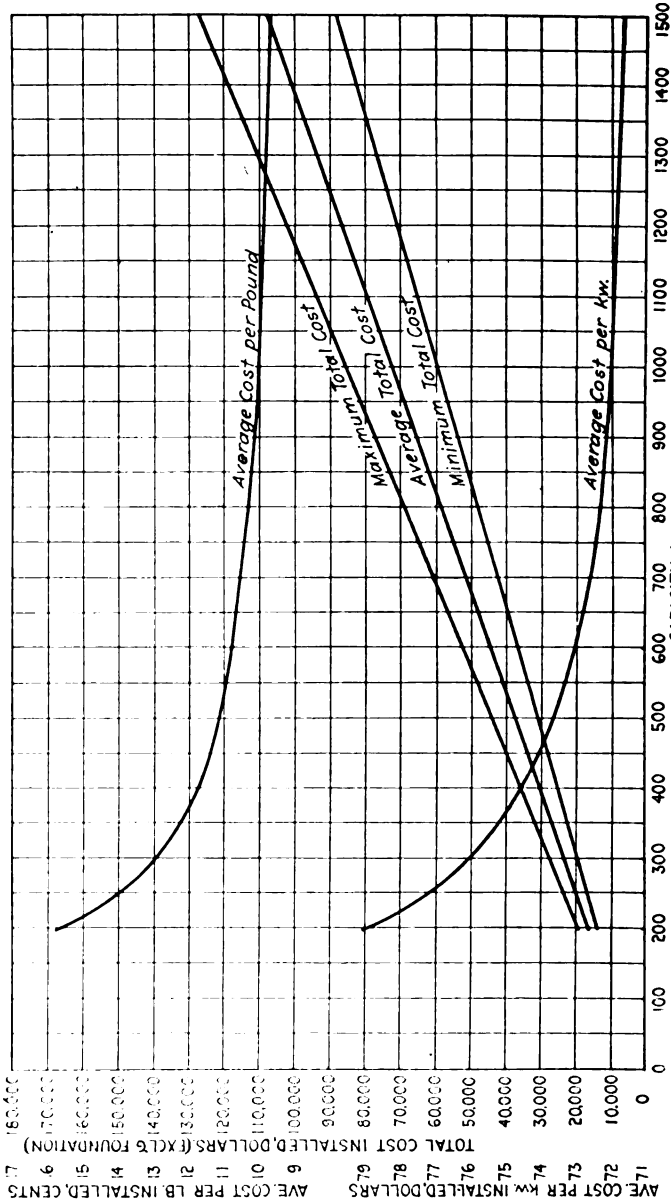


FIG. 8—HORIZONTAL TYPE (AMERICAN MANUFACTURE) PRODUCER GAS AND NATURAL GAS ENGINES, 4-CYCLE, TANDEM AND TWIN TANDEM, DIRECTLY CONNECTED TO 60-CYCLE GENERATORS FROM 200 TO 2000 KW. CAPACITY AT 80 PER CENT POWER FACTOR

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lower cost, many manufacturers have launched out to build them.

There are approximately 300 installations of medium- and heavy-duty oil engines, aggregating over 75,000 h.p., in operation in the United States.

On account of the very high cost of natural oils in countries that do not have an oil production of their own, the use of tar oil with a small addition of ignition oil in the Diesel engine is rapidly finding favor. Some oil engines operate satisfactorily on any fuel and especially the crude oils produced in this country, while others are limited to certain qualities. The recognition that coal is too valuable a fuel to be wasted in our present-day furnaces, is spreading, and much interest is being taken in the by-product coke oven and by-product gas producer plants, in hope that the production of tar oil, an artificial product, will aid to check the advance in price of natural liquid fuels. In this country the condition is different on account of the supply of rich natural oils, such as the light grades of crude oil produced in the eastern fields, as well as the heaviest grades produced by the California, Texas, Oklahoma and Mexican fields, which are largely asphalt base.

*Capacity.* Similar to the gas engine, the oil engine does not possess an inherent overload capacity in the same sense that the steam turbine does, hence, whatever overload is required must be provided by the manufacturer.

The oil engine is restricted in size for the same reasons given in the case of gas engines. The largest Diesel engine operating in this country is a 450 brake horse power double-unit vertical four-cycle three-cylinder type, whereas in Europe they have been built as large as 2500 brake horse power. There has recently been built in Germany a 2000 brake horse power horizontal double-acting, four-cycle, twin-tandem Diesel engine operating with tar oil, which promises interesting results.

*Efficiency.* The thermal efficiency of the oil engine varies slightly with the capacity. Unlike the gas engine, the thermal efficiency does not increase with the load beyond the capacity of the engine.

Figures of efficiency have been given at different times that cannot be substantiated. With oil having 19,000 B.t.u.'s (4788 large calories) per lb., (0.4534 kg.) the thermal efficiency and fuel consumption that may be expected at different percentages of normal full load rating, no allowance being made for auxiliaries, are shown in Fig. 9.

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At full load the fuel consumption is 0.64 lb. (0.29 kg.) per kw-hr. or 0.45 lb. (0.204 kg.), per brake horse power, and the thermal efficiency 28.2 per cent per kw-hr., or 29.8 per cent per brake horse power.

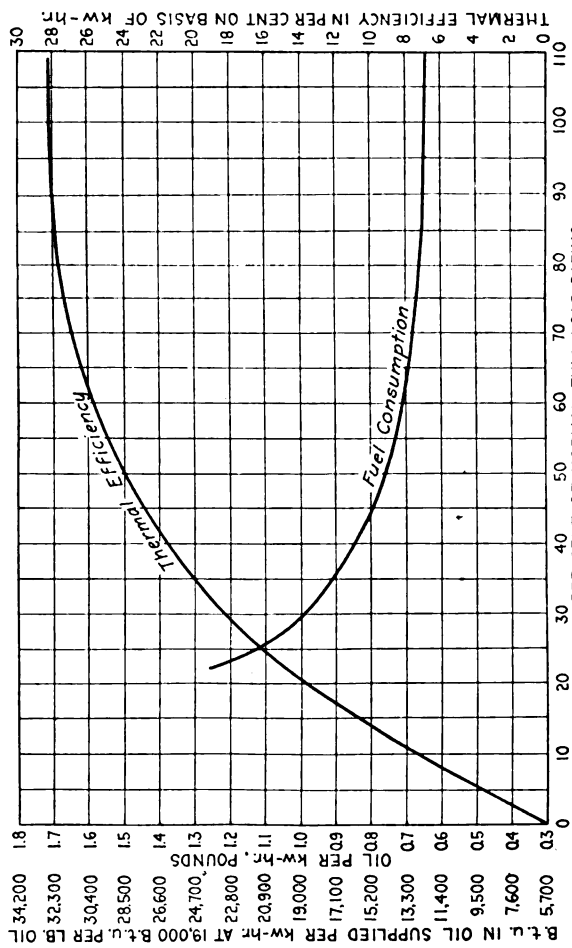


FIG. 9—VERTICAL DIESEL ENGINE, 4-CYCLE, 3 AND 6 CYLINDERS, DIRECTLY CONNECTED TO 60-CYCLE GENERATORS (AUXILIARIES NOT ALLOWED FOR)

The fuel consumption of the best oil engines to-day, made in large sizes, varies from 0.40 to 0.50 lb. per brake horse power, the highest fuel economy being obtained by the four-cycle type.

*Weight.* The Diesel engine is inherently massive for the same reason as the gas engine, namely, high temperatures and

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pressures, consequently the weight, including engine and generator, per kilowatt capacity increases with the size, as shown in Fig. 10.

It will be seen that the increase in weight from 40 to 160 kw. capacity is very rapid, while with sizes larger than 160 kw. it is not so pronounced.

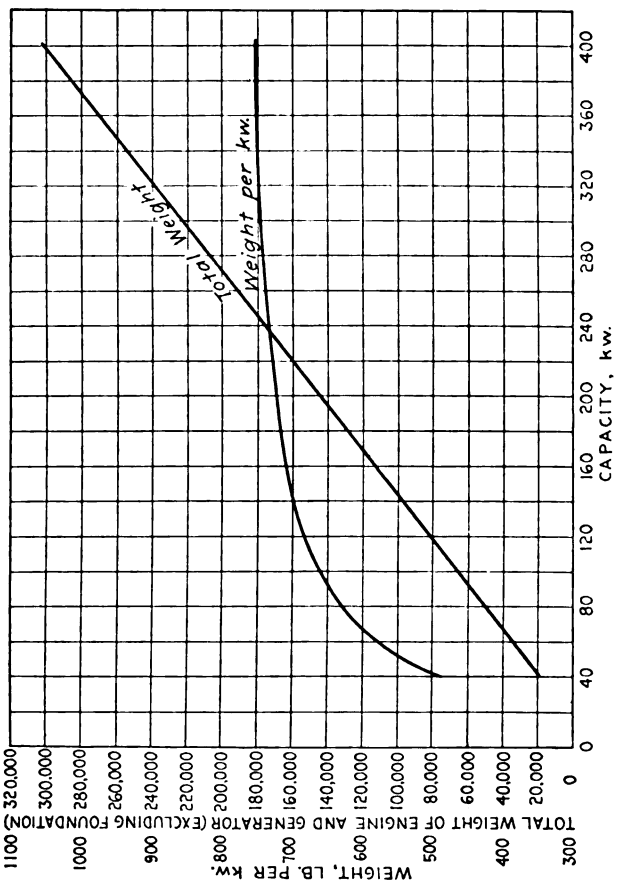


FIG. 10—VERTICAL DIESEL ENGINE (AMERICAN MANUFACTURE) 4-CYCLE, 3 AND 6 CYLINDERS, DIRECTLY CONNECTED TO 60-CYCLE GENERATOR, 40 TO 400 KW. CAPACITY.

High-compression Diesel-cycle crude-oil engines of the two- and four-cycle, single- and twin-cylinder, horizontal type, using a heavy grade of crude oil, are now being manufactured in America as large as 500 h.p. capacity, some companies standing ready to construct units of 800 h. p. capacity if required. Fig. 11 shows the average total weight and weight per kilowatt capacity for these machines.

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*Cost.* There have been so few oil engines driving generators of any appreciable size installed in this country that it is a difficult matter to tabulate any costs for comparative purposes with other prime movers. The most reliable figures available for the Diesel engine average approximately $95 per kilowatt installed, including engine and generator complete, but not the foundations, within 600 miles of factory. Fig. 12 gives the

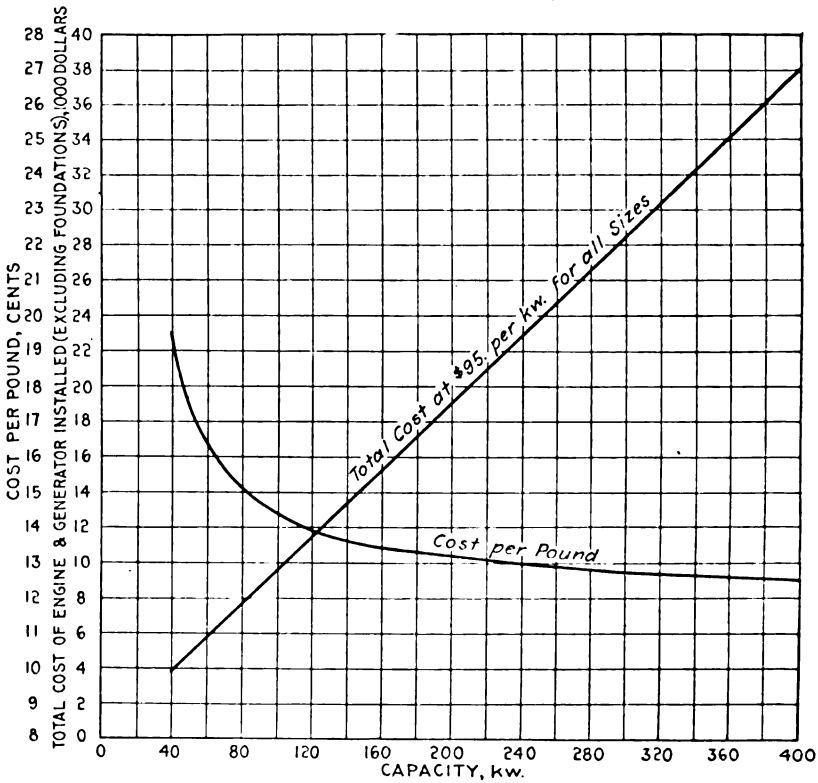


FIG. 11—VERTICAL DIESEL ENGINE (AMERICAN MANUFACTURE) 4-CYCLE, 3 AND 6 CYLINDERS, DIRECTLY CONNECTED TO 60-CYCLE GENERATOR, 40 TO 400 KW. CAPACITY

average total cost per kilowatt for all sizes at $95 per kw., also the cost per pound, which decreases but slightly for machines above 160 kw. capacity.

Important improvements in the construction of the vertical type Diesel engine are being made in this country, as well as in Europe, which will probably reduce the weight and consequently the unit cost.

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The average total cost, average cost per kilowatt, and average cost per pound of two- and four-cycle, horizontal, crude-oil engines, American manufacture, including engine and generator,

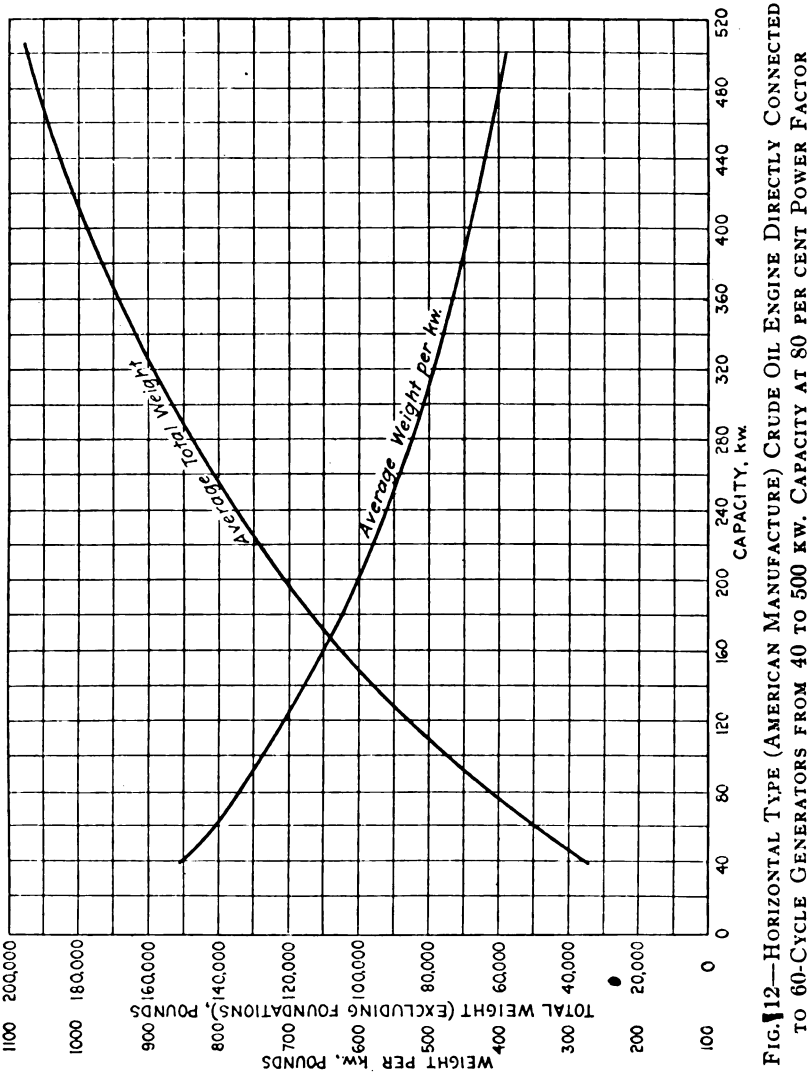


FIG. 12—HORIZONTAL TYPE (AMERICAN MANUFACTURE) CRUDE OIL ENGINE DIRECTLY CONNECTED TO 60-CYCLE GENERATORS FROM 40 TO 500 KW. CAPACITY AT 80 PER CENT POWER FACTOR

are shown in Fig. 13, corresponding to the weights given in Fig. 11.

There is considerable variation in the weights and costs of the horizontal type oil engines of the different manufacturers,

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and for this reason the average curve is given instead of the maximum and minimum. The weights and costs are fairly consistent for the single cylinders of all sizes, the greatest dif-

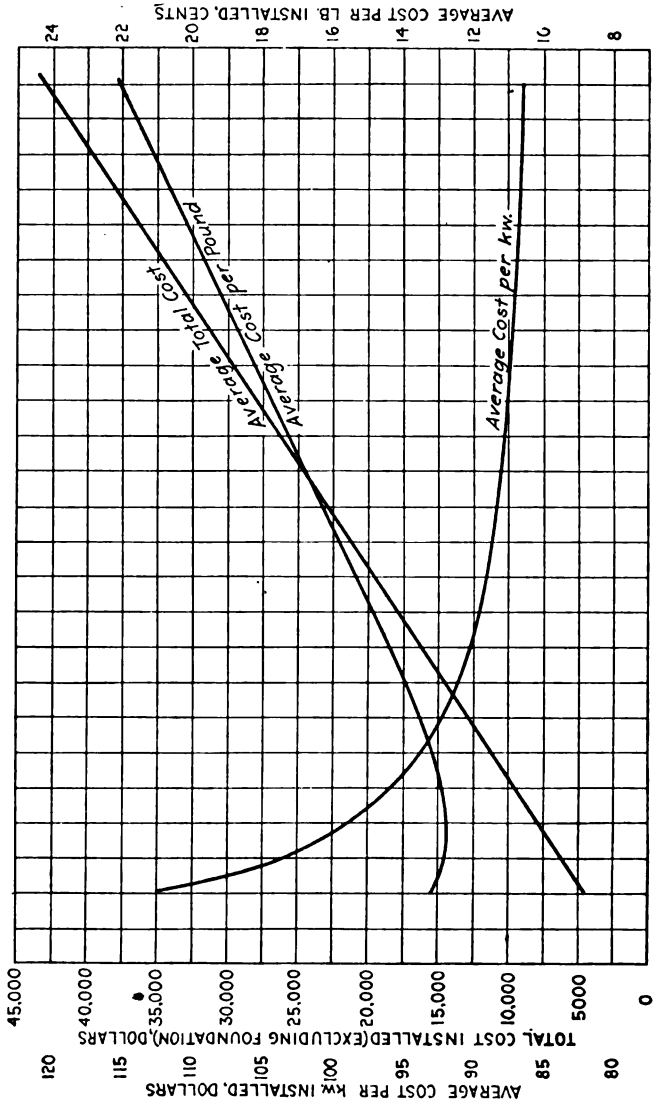


FIG. 13—HORIZONTAL TYPE (AMERICAN MANUFACTURE) CRUDE OIL ENGINE, DIRECTLY CONNECTED TO 60-CYCLE GENERATORS FROM 40 TO 500 KW. CAPACITY AT 80 PER CENT POWER FACTOR

ference being with the twin- and four-cylinder types. These curves hold fairly well for the so-called semi-Diesel horizontal type.

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## Hydraulic Turbines

The development of hydroelectric power installations has created new demands on the designers and manufacturers of hydraulic turbines for betterments in efficiency, power, speed, strength and size of turbine runners.

In early hydraulic installations, efficiency was frequently of small importance, but as the demands for power increased, and the capacity of sources of water supply became overtaxed, high efficiency became of importance.

In the case of modern hydroelectric developments, there are few sources of supply so great that the efficiency of the installed machinery is not of the highest importance. The demand on turbine designers and manufacturers for increased efficiency has been met by better design, better construction, and better finish; and as a result, the efficiency of turbines has been so increased that in the case of at least four different manufacturers, efficiencies of 90 per cent or over have recently been obtained at the hydraulic testing flume at Holyoke under the best conditions of gate, speed and head; and high efficiencies can now be maintained through considerable variations both of head and power, as will be seen by reference to Fig. 14.

Recent tests at Holyoke on a high specific speed 28-in. (71-cm.) vertical Francis type turbine, the results of which are shown in Fig. 15, represent the best that is being accomplished at the present time.

It will be seen that the efficiency remains fairly constant through a considerable variation in power. The efficiency at 90 per cent gate opening is 91.5 per cent and at full gate it dropped to 84 per cent.

For direct connection to comparatively high-speed electrical machinery, both capacity and speed, together with high efficiency, are common demands. A comparison of the power capacity of various types of wheels can best be made on the basis of the power of the unit wheels of the various types under the unit head. This unit power is represented by the equation

$$\varphi = \frac{P}{D^2 h^{3/2}}$$

$\varphi$ is the unit power of the unit wheel of the type considered under unit head,

$P$ is the power (h.p.) of any wheel under the head $h$,

$D$ is the diameter in inches of the wheel considered,

$h$ is the head in feet under which the power ($P$) is developed.

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In each case the best conditions of speed and efficiency are assumed to obtain.

In the original Boyden-Fourneyron turbine of 1849, the value of $\Phi$ was equal to..... 0.00032

This was increased by Swain in 1855 to.... 0.0008

By McCormick in 1860 to..... 0.0014

By a number of recent designers to values from 0.002 to 0.0024

And has been extended to..... 0.00388

in a recent design, without a reduction in efficiency below 87 per cent, an enormous increase in power which is quite worthy of note.

Capacity and speed are both often highly desirable for electric machinery if both can be extended without too great a sacrifice in efficiency. The combined capacity and speed may be compared by the speed power coefficients of the various types (see page 1409, Vol. XXXI, TRANSACTIONS A. I. E. E.), which may be termed the "specific power" of the wheel, and which is represented by the equation

$$\Phi_s = \frac{n^2 P}{h^{5/2}}$$

in which $n$ = the revolutions per minute of the wheel under the head $h$ and with the horse power $P$. The speed power coefficient $\Phi_s$, is the square of the coefficient of unity speed.

The value $\Phi_s = 10{,}000$ had barely been reached in 1910, but during the present year a designer has succeeded in increasing the value to $\Phi_s = 11{,}800$.

Such wheels are frequently of high value for low-head and high-speed conditions, but cannot maintain such high efficiencies under great ranges of head and loads as can be maintained with wheels of lower "specific power," such as are shown in Fig. 14.

Among the more recent improvements in the construction of hydraulic reaction turbine runners may be mentioned the construction of high-capacity runners of cast steel in single castings, thus giving great strength with large capacity under high heads to which such turbines could not previously be applied.

The recent successful construction of the large single reaction turbines for the Keokuk hydroelectric plant is also worthy of note. These turbines are 16 ft. 2 in. (4.875m.) in diameter and will operate at 57.7 revolutions per minute under a 32-ft. (9.75-m.) head. The runners weigh 73 tons each and develop 10,000 h.p. While greater power has previously been developed by single wheels

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under high heads, these wheels are remarkable for the amount of power developed under the low head utilized.

Since 1911, the trend has been toward the adoption of the single-runner, vertical-shaft turbine for low and medium heads. This change in type of unit is due to the recent progress in the

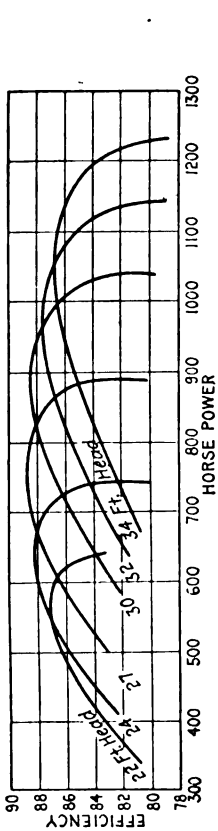


FIG. 14—WATERWHEELS

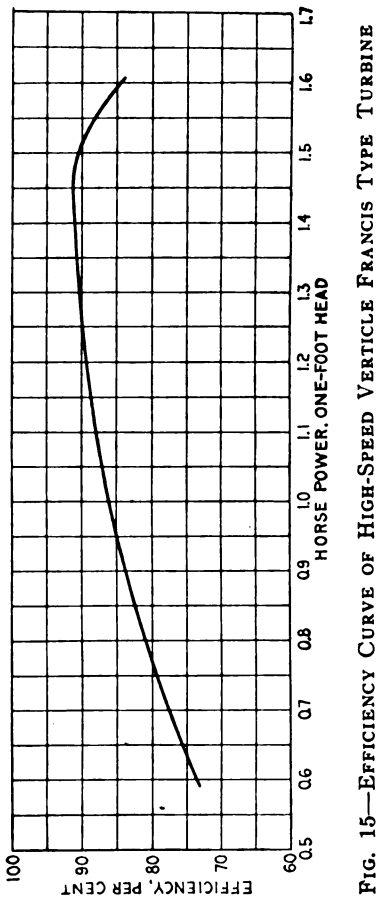


FIG. 15—EFFICIENCY CURVE OF HIGH-SPEED VERTICLE FRANCIS TYPE TURBINE

design and development of high-capacity runners, also the improvement in thrust bearings.

Prior to this time, the majority of turbines for low and medium heads were either of the vertical-shaft, multi-runner type, or of the horizontal-shaft, multi-runner type.

*Weight and Cost.* The weights and costs of hydraulic prime movers are not strictly comparable with the steam turbine, gas

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and oil engines, for in the case of the thermodynamic prime movers, the conditions are more or less fixed and the costs relatively uniform, whereas with the water turbine they vary between fairly wide limits, depending upon the conditions under which they are to be operated. The head, kind of flume, open or closed, setting vertical or horizontal, single or multiple, material in runner, which may be made of cast iron, cast steel, gun metal, bronze, etc., depending upon the service conditions, are some of the factors that cause the price and weight to vary materially. With a given head, the greater the power of the turbine the less the unit cost. With a given head and power, the higher the speed the less the unit cost. On the other hand, with a given power, the lower the head the greater the unit cost. For illustration, a water turbine developing 50 h.p. under a 30-ft. (9.14-m.) head, and costing $18 per horse power, will develop approximately 300 h.p. under a 100-ft. (30.4-m.) head, and will cost only $3 per horse power, assuming other conditons equal. In reality the cost of the turbine under the 100-ft. (9.14 m.) head would be slightly higher than $3 as the construction would naturally be more expensive.

In general it can be said that the cost of hydraulic turbines and generators larger than 200 kw. capacity will vary from $5.0 to $10 per kilowatt installed, exclusive of foundations.

With the broader field now covered by turbine design and construction, the necessity for careful selection has become most important, and the hydraulic engineer can at the present time secure hydraulic turbines of the best character and design only by careful attention to the intelligent analysis of turbine possibilities, and the selection of wheels suited to the particular conditions of head and load under which such turbines are to operate.

## Finance and Economics

*Investment and Fuel Costs.*

*a. Heat Engines.* In comparing the various types of prime movers, conclusions are often reached, largely from a study of the cost of fuel, without any reference whatever to the total cost of power and the relative investment costs. As it is not within the scope of this paper to include operating and maintenance costs for the entire plant, investment costs of the units and fuel costs are shown plotted in conjunction with the percentage of normal full-load rating in Figs. 16 and 17, for making an economic study of the various types of prime movers.

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The impression that gas and oil power invariably imply a lower cost of generation is constantly losing ground through the critical analysis of the elements of power costs. Fuel is

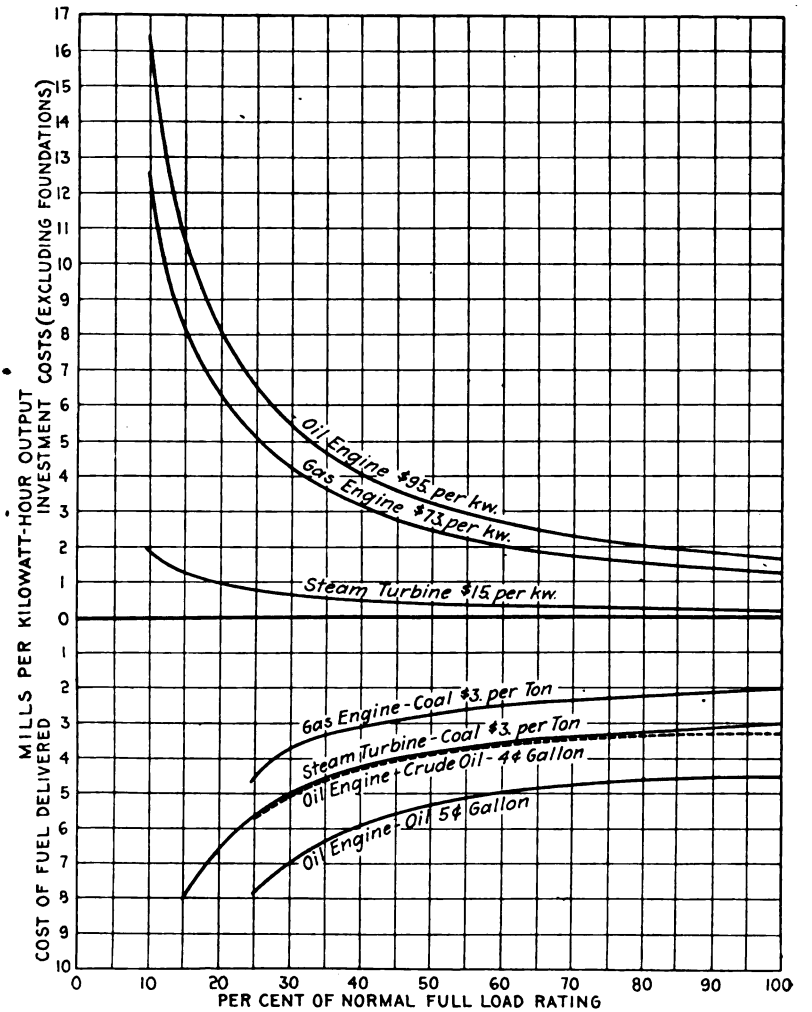
MILLS PER KILOWATT-HOUR OUTPUT
INVESTMENT COSTS (EXCLUDING FOUNDATIONS)
COST OF FUEL DELIVERED
Oil Engine $95 per kw.
Gas Engine $73 per kw.
Steam Turbine $15 per kw.
Gas Engine - Coal $3 per Ton
Steam Turbine - Coal $3 per Ton
Oil Engine - Crude Oil - 4¢ Gallon
Oil Engine - Oil 5¢ Gallon
PER CENT OF NORMAL FULL LOAD RATING

FIG. 16—RELATIVE INVESTMENT AND FUEL COSTS OF A 750-KW. STEAM TURBINE, GAS ENGINE, AND OIL ENGINE, INCLUDING DIRECT-CONNECTED 60-CYCLE GENERATOR OPERATING AT DIFFERENT PERCENTAGES OF NORMAL FULL LOAD

only a fraction of the total cost of power, and there are conditions where it is overbalanced by other costs.

Claims have been repeatedly made that steam turbines use

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two and one-half times the amount of fuel consumed by gas engines, but these statements are without foundation. Before any fair comparison can be made of fuel consumptions, records should be kept over a reasonably long period and the coal reduced to a common basis as to B.t.u. per pound and the percentage lost in refuse.

The curves plotted in Fig. 16 are for small machines of 750-kw. capacity—the steam turbine a single unit costing $15 per kilowatt, the gas engine a single unit costing $73 per kilowatt, and the oil or Diesel engine a double unit costing $95 per kilowatt. These prices are for the prime mover and generator delivered and erected (exclusive of foundations) within 600 miles of the factory.

The investment costs are taken at 11 per cent for the steam turbine and 15 per cent for the gas and oil engines. In investment costs are included interest, taxes, insurance and amortization fund, that is, an arbitrary percentage that should be set aside and the percentage corrected, if necessary periodically, so that when the apparatus is condemned on account of obsolescence or inadequacy, there will be a fund which will meet the expense (see "Power Costs" A. I. E. E. PROCEEDINGS, May, 1913).

Coal for both the steam turbine and gas engine is taken at $3 per ton (1016 kg.) having 14,500 B.t.u. (3654 large calories) per lb. (0.4534 kg.) delivered alongside the dock. On account of the wide fluctuation in price of the same oil at the same locality, two figures are used, namely, four and five cents per gallon (3.785 litres). All auxiliary costs are included, but stand-by costs are not, as these vary widely with the conditions of operation.

Adding the investment and fuel costs for any percentage of normal full load rating, the steam turbine will be found to be slightly less than the gas, and considerably less than the oil engine. Even with stand-by losses allowed, the turbine will still have the advantage over the gas engine loads below 80 per cent full load rating.

The investment costs are computed on the normal full-load rating, and if advantage is taken of the overload capacity of the turbine which is approximately 25 per cent for 24 hours, the cost per kilowatt-hour during such periods of maximum capacity will be less than shown by the curve. This does not apply to gas and oil engines, as what little overload capacity may be allowed in these machines is for a short period of two hours or even less.

Another set of curves is plotted in Fig. 17, showing a single turbine unit of 20,000-kw. capacity, costing $7.50 per kilowatt, ten 2000-kw. gas-engine units costing $65 per kilowatt, and

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forty 500-kw. oil-engine units at $85 per kilowatt. In a plant of this capacity the gas and oil engines are practically out of the running, with these fuel costs.

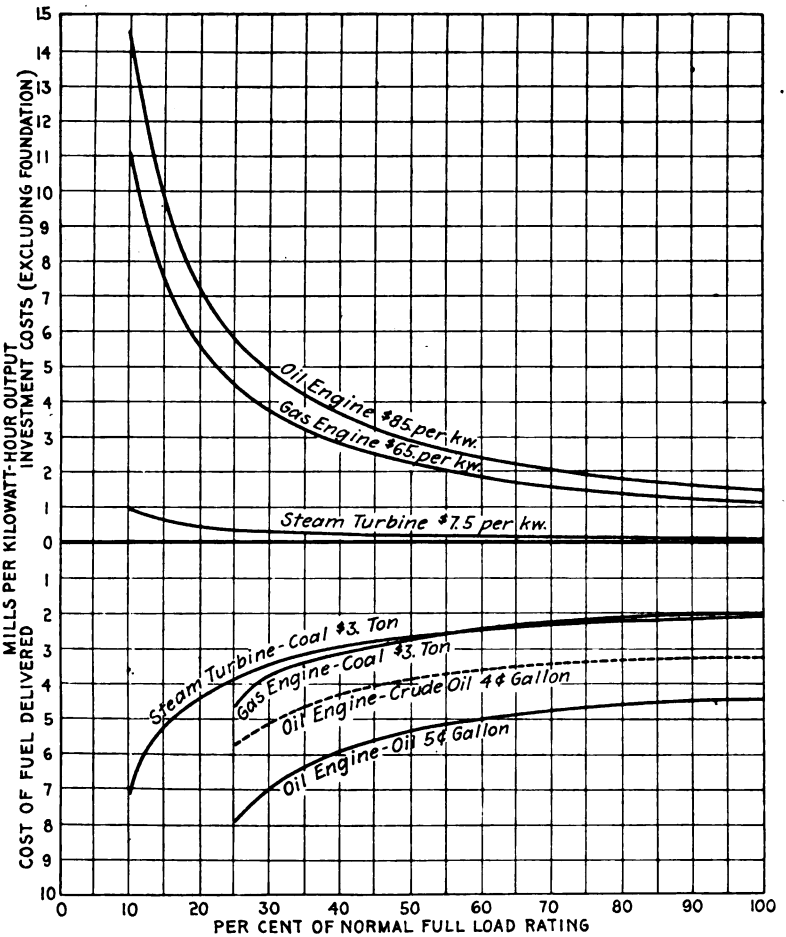
MILLS PER KILOWATT-HOUR OUTPUT
INVESTMENT COSTS (EXCLUDING FOUNDATION)
COST OF FUEL DELIVERED
Oil Engine $85 per kw.
Gas Engine $65 per kw.
Steam Turbine $75 per kw.
Steam Turbine - Coal $3. Ton
Gas Engine - Coal $3. Ton
Oil Engine - Crude Oil 4¢ Gallon
Oil Engine - Oil 5¢ Gallon
PER CENT OF NORMAL FULL LOAD RATING

FIG. 17—RELATIVE INVESTMENT AND FUEL COSTS OF PRIME MOVERS DIRECTLY CONNECTED TO 60-CYCLE GENERATORS OF 20,000 KW. CAPACITY OPERATING AT DIFFERENT LOADS

Steam Turbine—1 unit 20,000-kw. normal rating.
Gas Engine—10 units 2000-kw. " "
Oil Engine—40 units 500-kw. " "

In computing the cost of fuel the coal was put on the same basis, namely, 10,825,000 B.t.u. (2,727,868 large calories) per dollar, whereas the oil at 4 cents per gallon is equivalent to

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3,718,000 B.t.u. (936,925 large calories) per dollar. This may look as though the steam turbine and gas engine were being favored, but in comparing prime movers as they stand to-day they must be considered in connection with the prevailing cost of fuel. While it is possible to get a cheaper coal than $3 per ton (1016 kg.) with 14,500 B.t.u. (3654 large calories) per lb. (0.4534 kg.), it is a question whether many more B.t.u's. (large calories) of natural oil per dollar can be obtained, except in a few localities.

If natural instead of producer gas is considered, it would cost about 10 cents per 1000 cu. ft. (28.317 cu.m.), which is a reasonable figure, as the price varies from 5 to 25 cents per cubic foot, depending upon the location of the well.

At 40 per cent of normal full-load rating, the investment cost for the gas engine is approximately 90 per cent of the fuel cost and for the oil engine using oil at four cents per gallon (3.785 liters) it is about 80 per cent, whereas with the steam turbine it is only 7 per cent.

If we assume for illustration, that in a small plant it is possible to obtain a horizontal semi-Diesel installation, including engine and generator delivered and erected, excluding foundations, for $73 per kilowatt, and that oil can be purchased for 3.5 cents per gallon (3.785 liters) delivered, it will be seen from Fig. 16 that while the cost of fuel will be slightly in favor of the oil engine, the sum of the ordinates above and below the axis for any percentage of load will be in favor of the steam turbine. With larger installations it will be seen by referring to Fig. 17 that the turbine has decidedly the advantage.

All these illustrations are on the basis of the normal full-load rating of the plant, however, if reserve capacity is allowed for to insure continuity of service, the investment costs for the gas and oil engines will be proportionately higher than for the steam turbine.

From a study of these curves it will be seen that the ratio of cost of steam to gas and oil units is decidedly in favor of the former so that gas and oil power becomes severely handicapped in large work owing to the proportionately greater investment burden. And, unless the price of coal rises materially above the present value, the gas and oil engines will find limited application in stations of any appreciable size, except under very favorable circumstances, where natural gas, by-product gas or some artificial fuel oil can be secured at low prices. If maintenance cost and the additional investment cost required to assure re-

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liability or continuity of service are included, the steam turbine will stand out more prominently.

*b. Hydraulic Turbines.* The redeeming feature of the watert urbine, which gives it an advantage over other prime movers, is the absence of fuel. As a result, the operating expenses are practically the same whether the plant is working 10 or 24 hours per day. On the other hand, the investment cost is influenced by the load factor, but it is doubtful in any case whether the water turbine and generator will exceed twice that of the steam turbine and generator on the basis of 11 per cent. When the investments costs include an adequate supply of auxiliary capacity to supplement the deficiency in stream flow, the difference between the investment costs of prime movers plus the fuel costs, at any percentage of normal full load rating, will not be so marked, as the investment costs of the units of the hydroelectric plant will not only be much higher than a straight steam plant, but in addition, there will be fuel costs for the reserve units. In fact, with the same class of service, and the reliability charge in the form of duplication of units or steam reserve, the straight steam turbine units will in many cases be more economical.

In low-priced fuel districts the hydraulic turbine is only a competitor of the steam turbine where the development costs are moderate and the load factor reasonably high.

More attention is now being given to the important relation between the efficiency and durability of the water turbine than has been in the past. It is the opinion of some engineers that the most efficient turbine, if operated too constantly at low gate opening is likely to show some pitting if the head is high, and they recommend that turbines of high specific speed be kept as closely loaded as possible to the point of maximum efficiency, while with turbines of lower specific speed it is not necessary to operate within such close limits.

*General.* The proportion of the total investment cost of a 20,000-kw. plant represented by the prime mover and generator for the various types of units, is approximately as follows:

| Prime mover | Total investment cost per kw. | Cost of prime mover and generator per kw. | Percentage of total invest't |
|---|---|---|---|
| Steam turbine..... | 65.00 | 7.50 | 15 |
| Gas engine..... .. (Producer gas) | 140.00 | 65.00 | 46.5 |
| Oil engine..... | 120.00 | 85.00 | 71 |
| Hydraulic turbine .. | 125.00 | 12.00 | 9.6 |

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The unit costs are the average values obtained from the cost curves given above, while the total costs were estimated and are only approximate, especially in the case of the oil engine, as it is impossible to obtain reliable data for this type of installation.

Considering the different types of prime movers in connection with the total investment cost of the plant, it is evident from a study of curves similar to Figs. 16 and 17, developed on a load factor and total cost basis, that with a very poor load factor the all-important point is to keep down the fixed charges, as they are of vastly greater importance than any possible gain in efficiency due to a better type of prime mover of the same class. This is true of any plant, and the curves will show the futility of attempting to carry peak loads by means of water turbines, gas

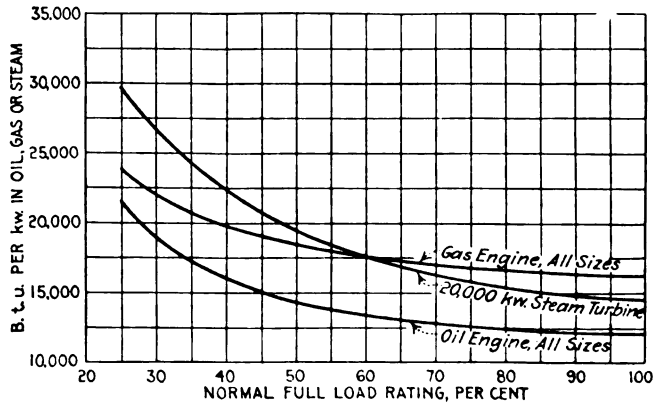


FIG. 18—RATES OF HEAT CONSUMPTION PER KW. AT DIFFERENT PERCENTAGES OF NORMAL FULL-LOAD RATING

and oil engines or any prime mover that necessitates a large investment per kilowatt.

*Efficiency and Heat Consumption.* Figs. 18 and 19 are presented to show conservative thermal efficiencies and heat consumptions in B.t.u. per kilowatt-hour at different percentages of normal full-load rating, for two sizes of steam turbines and for all sizes of gas and oil engines, reckoned on the heat in the steam, gas or oil delivered to the throttle valve, and do not include boiler or producer losses or auxiliaries.

It is evident that as the larger sizes are approached the inequality between the steam turbine and gas engine steadily vanishes until finally the former exceeds the latter. It is interesting to note that at normal full-load rating the thermal efficiency of

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the 20,000-kw. steam turbine, which is based on 175 lb. steam pressure and 100 deg. superheat, is 24.2 per cent, and the producer or natural gas engine 23.8 per cent, both referred to kilowatt-hour output. Referring to Fig. 2, it will be seen that the average thermal efficiency of steam turbines larger than 14,000 kw. is between 24 and 25 per cent, and the maximum value for very large machines is a little below 25.5 per cent.

An important feature of the steam turbine and especially the oil engine, is that the efficiency does not materially decrease

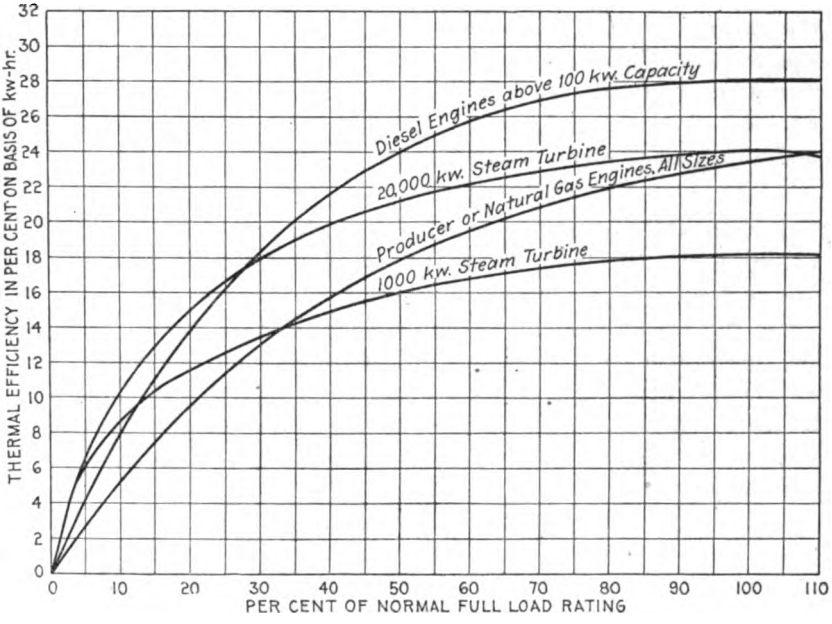


FIG. 19—THERMAL EFFICIENCY OF PRIME MOVERS (AUXILIARIES NOT ALLOWED FOR)

until the load falls below 25 per cent of the normal rating, whereas the gas engine changes rapidly.

In small plants with a low load factor, efficiency may be a secondary matter compared with investment cost, and the cost of maintenance and reliability.

*Maintenance and Reliability.* On account of the high mechanical stresses inherent in the gas and oil engines, and heavy reciprocating masses, there is necessarily greater maintenance and repair cost, also a lower reliability of ser-

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vice and a higher class of attendance than for either the steam or water turbine units. The reliability of the gas and oil units has not been sufficiently established to warrant their adoption for reasonably large power stations operating 24 hours daily, without the plant being over-burdened with some type of reserve and consequently excessive investment costs.

### Space Economy

This factor affects the investment cost of power, and is especially of very great importance for plants of any appreciable size in large cities or where property is expensive. For different sizes of the various types of prime movers the number of kilowatts per square foot of floor space occupied, is from 10 to 15 for horizontal steam turbines, and from 0.5 to 0.8 kilowatt for gas and oil engines. Where a number of gas and oil engines are installed and the passage ways included, the contrast will be still greater.

### Summary

Perhaps the most remarkable fact brought out in this report is shown in Fig. 19, where we find that the large steam turbine has now passed the gas engine in thermal efficiency and the only prime mover surpassing it is the Diesel type of oil engine. The oil engine reaches a maximum efficiency of about 28 per cent as compared to about 24 per cent for the latest type of 20,000-kw. high-vacuum steam turbine, and there is every prospect that at least 26 per cent will be realized before the end of the current year.

The present limit in size of the Diesel type engine seems to be about 1800 kw., so that for plants in excess of 15,000 kw. in capacity the number of units and the space occupied by them becomes excessive. Just what their maintenance under the high cylinder temperature will be is dubious, as there are not sufficient data available to enable the Committee to report.

Figs. 16 and 17 summarize the whole prime mover situation in the combined curves of investment and fuel costs, as by taking the sum of the ordinates at any percentage of the rated load it will be seen that the steam turbine is far more economical than any other type of heat engine.

In conclusion the authors wish to acknowledge their indebtedness to Mr. D. W. Mead, a member of this committee, for the curves of Fig. 14 and a portion of the section on hydraulic turbines, and also the kindness of a number of manufacturing companies in furnishing the necessary data.

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# VOLTAGE TESTING OF CABLES

BY W. I. MIDDLETON AND CHESTER L. DAWES

ABSTRACT OF PAPER

In this country rubber compound, paper, and cambric are generally used for cable insulation. From the formula $S = \frac{0.868\,V}{d \log_{10} \frac{D}{d}}$, the stress at any point in a homogeneous insulation may be determined. The minimum stress and the maximum allowable voltage occur when the conductor is 10/27 of the sheath diameter. The present irrational practise of testing cables should be standardized to conform to this formula or a modification of it.

Over-stressing of the insulation is accompanied by a change of insulation resistance and electrostatic capacity.

No one factor of safety is applicable to every cable system, but one must consider the conditions of operation as well.

In testing the voltage may be applied: (1) by submersion; (2) between the conductor and metallic sheath; (3) between wires. The submersion test is the most severe. A sine wave is desirable for testing purposes, but rarely occurs in a commercial generator under these severe conditions of load. Reactance cannot always be used successfully to reduce the volt-ampere load on the generator.

With a distored wave an a-c. voltmeter gives only a poor indication of the maximum voltage. The writers have devised an instrument based on the oscillograph principle, with which the maximum voltage may be determined, regardless of wave form.

THE design of cables is largely dependent on data obtained from voltage tests made on commercial lengths. Such tests are usually conducted in the testing-room but are frequently made after the cable has been installed. The importance of this subject has led the writers to present such data as may seem either useful or of interest in connection with the design or testing of cables, and further, to enumerate some of the difficulties encountered in making such voltage tests, together with the methods adopted to eliminate these difficulties.

## INSULATING MATERIALS

In this country, three materials are in general use for the insulation of wires and cables; rubber compound, varnished cambric, and paper.



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Rubber compound is the oldest, and is the only one that can be used under all conditions without the aid of a lead sheath. Its composition is more complex than that of the others, involving pure rubber, certain mineral ingredients, and hydrocarbons. The number of such ingredients and the proportion of each that can be used has allowed a great number of compounds to be made and has led to considerable discussion as to the value of some of these as insulating materials.

Paper as an insulation for wires and cables is used in two ways: wrapped on loosely and kept dry, as in telephone cables, or put on tightly and saturated with some good insulating oils or compound. The insulating properties of this class of cable depend absolutely on the soundness of the lead sheath.

Varnished cambric is the most recent material used for cable insulation and stands between rubber and paper; it has a number of good qualities. Being a cotton fabric coated on both sides with several films of insulating varnish, it is almost waterproof, and may be submerged in water for a considerable length of time without undue deterioration. In the process of manufacture, the varnished cloth is applied spirally in the form of tape, a viscous insulating compound being simultaneously applied between layers.

## Voltage and Stress Formulas

Theoretically, the stress at any point on a homogeneous cylindrical insulation may be determined from the following formula:

$$S = \frac{0.434\ V}{X \log_{10} \frac{R}{r}} \qquad (1)$$

where $V$ = volts impressed between conductor and sheath,
$r$ = radius of the conductor,
$R$ = radius of the insulation,
$X$ = distance from the axis to the point in question,
$S$ = stress in volts per unit thickness of insulation at this point.

The stress will be a maximum at the surface of the conductor. Therefore letting $X = r$, $r = d/2$, and $R = D/2$, the stress at the surface of the conductor becomes

$$S = \frac{0.434\ V}{\frac{d}{2} \log_{10} \frac{D}{d}} = \frac{0.868\ V}{d \log_{10} \frac{D}{d}} \qquad (2)$$

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where $d$ = diameter of the conductor,
$D$ = diameter of the insulation.

This relation is shown in Fig. 1.

With $D$ and $V$ fixed, the maximum stress at the surface of any insulated wire will be inversely proportional to $d \log_{10} \frac{D}{d}$.

It will therefore diminish with an increase in the diameter of the conductor, until a minimum is reached, after which the stress will increase with further increase of conductor diameter. This minimum may be found by differentiating formula (**2**), and

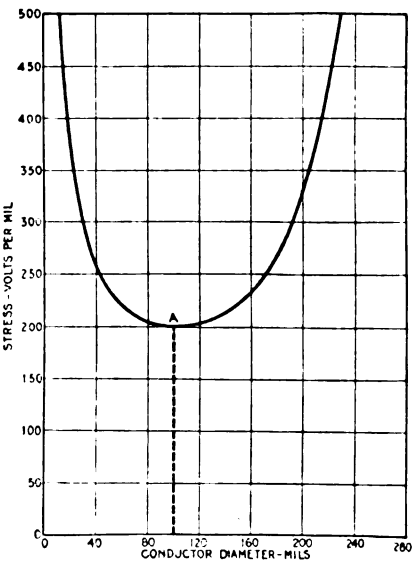


FIG. 1—CURVE OF STRESS AND CONDUCTOR DIAMETER.
Voltage (V) constant at 10,000. Diameter over insulation (D) constant at 272 mils.

equating to zero, and the value of $d$ corresponding thereto is found to be $D/\epsilon = D/2.72$ where $\epsilon$ is the Napierian base. This relation plotted with volts per mil as ordinates and conductor diameter as abscissas, is shown in Fig. 1. Point $A$ shows the point of minimum stress. The wire diameter for minimum stress is about 10/27 of the diameter of the insulation.

If in formula (**2**), $D$ and the maximum allowable stress $S$ are kept constant, and the voltage is allowed to vary with the conductor diameter, we have

$$V = \frac{Sd}{0.868} \log_{10} \frac{D}{d} \qquad (3)$$

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This relation is shown in Fig. 2. Under these conditions the maximum voltage that we may impress between the conductor and the outside, without exceeding the allowable stress, occurs when $d = D/2.72$.

This does not mean, however, that if this maximum voltage were impressed upon the cable when $d$ is less than $D/2.72$ the insulation would break down, but rather that the wall of insulation between the diameter $D/2.72$ and the conductor would be

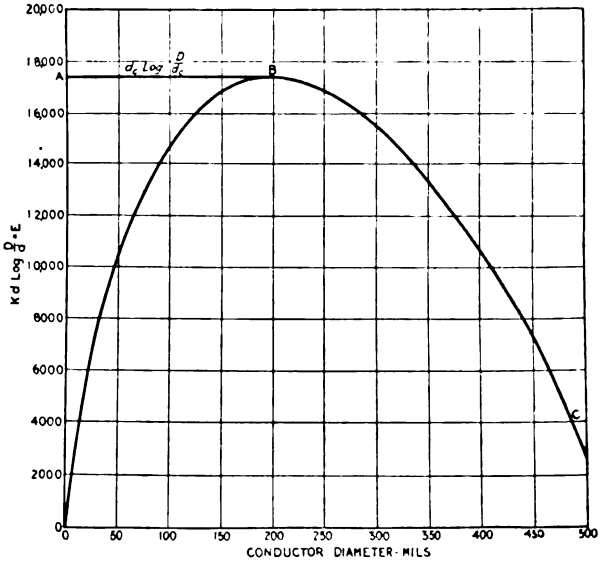


FIG. 2—RELATION BETWEEN TEST PRESSURE AND CONDUCTOR DIAMETER.

$E = K\ d \log D/d$. $K = 200$. $D = 544$ mils. Stress constant.

All wires having the same outside diameter whose conductor diameter is equal to or less than D/2.72 ( $= d_c$) should have the same breakdown voltage.

stressed beyond the allowable limit. The layer nearest the conductor is under the maximum stress, and the stress in any other layer is inversely proportional to its distance from the center if the electrical characteristics of the insulation remain unchanged. Theoretically, then, all cables having $d$ less than $D/2.72$ should break down at the same voltage, hence follow the line $ABC$, if it be assumed that the voltage drop across the over-stressed layer is practically zero.

Although there has been no evidence, so far as the writers

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know, that these inside layers are actually broken down under these conditions, it is a well-known fact that the dielectric constant of an over-stressed dielectric is greater than the normal constant before breakdown, and this tends to reduce the voltage drop across the inner layers and throw more stress on the outer wall. Whether or not this be true, experience indicates that the breakdown occurs along the line $AB$, Fig. 2, and little or nothing is gained in making $d$ less than $D/2.72$.

The following formula has therefore been adopted as most

TABLE I

Values of $d \log \frac{D}{d}$. $D$ and $d$ in mils

| Wall (in.) | Size Wire B. & S. No. 14 | No. 12 | No. 10 | No. 8 | No. 6 | No. 4 | No. 1 Std. | 4/0 Std | 1,000,000 Cir. Mils. |
|---|---|---|---|---|---|---|---|---|---|
| 1/32 | 19.1 | 20.0 | 21.3 | 21.9 | 22.8 | 23.9 | 24.8 | 25.6 | 26.2 |
| 3/64 | 25.2 | 27.1 | 28.9 | 30.7 | 33.0 | 33.7 | 36.0 | 37.6 | 38.8 |
| 2/32 | 30.3 | 33.0 | 36.4 | 38.0 | 40.5 | 42.4 | 46.0 | 49.4 | 51.6 |
| 5/64 | 34.5 | 38.0 | 41.1 | 44.2 | 47.6 | 50.4 | 55.5 | 59.5 | 64.0 |
| 3/32 | 38.4 | 42.2 | 46.3 | 50.4 | 54.4 | 58.0 | 64.5 | 70.0 | 75.5 |
| 7/64 | 41.6 | 46.0 | 50.8 | 55.6 | 60.0 | 65.1 | 73.0 | 79.6 | 87.1 |
| 4/32 | 44.6 | 49.5 | 54.9 | 60.4 | 65.9 | 71.0 | 80.7 | 89.0 | 98.4 |
| 9/64 | 47.2 | 52.7 | 58.6 | 64.8 | 70.9 | 76.9 | 88.1 | 97.6 | 108.9 |
| 5/32 | 49.7 | 55.5 | 62.2 | 69.0 | 75.6 | 82.5 | 95.5 | 107.0 | 119.2 |
| 6/32 | 54.0 | 60.8 | 68.3 | 76.3 | 84.5 | 92.5 | 108.5 | 123.2 | 141.1 |
| 7/32 | 57.7 | 65.3 | 73.8 | 82.9 | 92.2 | 102.0 | 121.0 | 138.9 | 161.2 |
| 8/32 | 61.0 | 69.3 | 78.6 | 88.8 | 99.1 | 110.0 | 132.0 | 153.0 | 180.4 |
| 9/32 | 64.0 | 72.9 | 83.0 | 94.1 | 105.3 | 117.3 | 141.0 | 166.2 | 198.8 |
| 10/32 | 66.3 | 76.2 | 87.0 | 98.9 | 111.3 | 124.5 | 150.5 | 179.3 | 217.0 |

nearly representing the breakdown stress for small conductors with a heavy wall of insulation.*

$$S = \frac{0.868\ V}{d_c \log_{10} \frac{D}{d_c}} \qquad (4)$$

where $d_c = D/2.72$.

*_Potential Stresses in Dielectrics_, by H. S. Osborne, TRANS. A. I. E. E., Vol. XXIX, part 2, p. 1553.

Discussions, by W. I. Middleton, p. 1587; Henry A. Morss, p.1589; Wm. A. Del Mar, p. 1614.

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The maximum voltage that may be safely impressed upon a cable of a given insulating material is proportional to $d \log_{10} \frac{D}{d}$, and to a constant $K$, depending on the quality of material (formula **3**).

Values of $d \log_{10} \frac{D}{d}$ are given in Table I, for walls from 1/32 in. (0.794 mm.) to 10/32 in. (7.94 mm.) thick on various wires from No. 14 B. & S. to 1,000,000-cir. mil cable, and these values are plotted in Fig. 3. These tables and curves are very

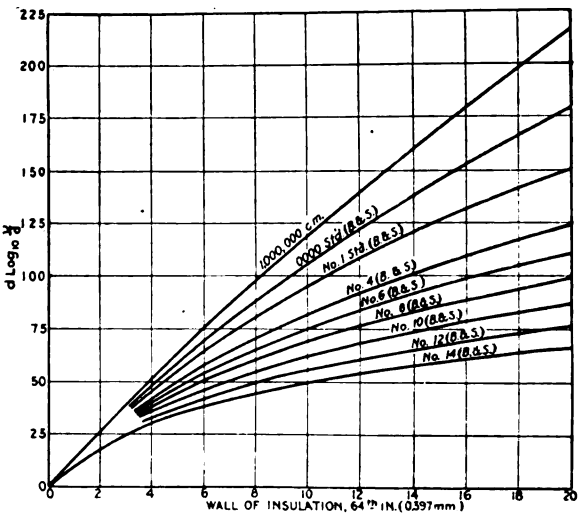


FIG. 3—RELATION BETWEEN $d$ LOG$_{10}$ $D/d$ AND WALL OF INSULATION. "$d$" AND "$D$" IN MILS

useful in the application of the formula to cable testing, for the value of $K$ only needs to be known to determine the allowable voltage test or proper diameter. When $d$ is expressed in mils, $K$ varies from 100 to 250 for rubber compounds, is about 250 for cambric, and for paper with thin walls is much less than 250 but is greater than this for walls exceeding 10/32 in. (7.95 mm.)

## STANDARDIZATION OF VOLTAGE TESTS

Until recently no attempt has been made to standardize voltage tests on insulated wire and cables with reference to the theoretical stress. The result is a chaotic condition of affairs. A very

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common rule has been to specify a test of $2\frac{1}{2}$ times the working pressure, the feeling being that this allows a good factor of safety. This rule might be satisfactory if the wires were all of one size and the same wall of insulation used for each working pressure. As such is not the case, the only rational way to test all cables is by the $d \log_{10} \frac{D}{d}$ rule or a modification of it.

On October 1, 1905, the Underwriters' Laboratories specified that all Code wires for voltages between 0 and 600 volts should be tested after ten hours immersion in water, with 1500 volts (alternating current) for not less than five seconds. That specification showed the influence exerted on most engineers at that time by the factor of $2\frac{1}{2}$ times the working pressure.

A little study of Fig. 3 together with the sizes of wires and walls of insulation made under the code specifications shows how absurd this test was. The conductors varied from No. 14 to 1,000,000 cir. mils and larger (0.064 to 1.156 in.) or (1.63 mm. to 29.4 mm.) in diameter; the wall of insulation from 3/64 in. (1.19 mm.) to 7/64 in. (2.78 mm.), (0.469 to 0.109 in.). If the 3/64 in. (1.19 mm.) wall of insulation on the No. 14 would stand 1500 volts, it should surely stand much more than this on the 1,000,000 cir. mil. It would therefore be possible for the 1,000,000-cir. mil cable to meet this test even were the wall of insulation defective or actually less than 3/64 in. (1.19 mm.) in places, whereas the main object of the voltage test is to break down any such faults.

The 1911 Code specifications for 0 to 600 volts have, in part, remedied this defect by calling for a test of the 1,000,000 cir. mil at 3500 volts, but at the higher voltages they still hold to $2\frac{1}{2}$ times the working pressure. The specifications of some of the largest buyers in the country to day are equally inconsistent.

This is a lamentable condition. It allows too much variation in the dielectric strength of the insulating materials. Some of this variation may be due to ignorance, and some may be intentional. When a cable is tested at only one-half the voltage to which it should be subjected, there results in many instances a carelessness in its manufacture. The writers believe that too little has thus far been accomplished in the line of the standardization of cable testing, when compared with other branches of engineering.

The following tests, in Tables II and III, are recommended for high- and medium-voltage cables, respectively. Table IV, on

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TABLE II

RECOMMENDED VOLTAGE TESTS FOR HIGH-VOLTAGE CABLES.

30 per cent Para Rubber

| Wall of insulation (in.) | 3/64 | 2/32 | 5/64 | 3/32 | 7/64 [1] | 4/32 | 5/32 | 6/32 | 7/32 | 8/32 |
|---|---|---|---|---|---|---|---|---|---|---|
| 550,000 cir. mil and larger | | | | | 14,000 | 16,000 | 19,000 | 22,000 | 25,000 | 28,000 |
| 500,000 cir. mil to 250,000 cir. mil. | | | | | 13,500 | 15,000 | 18,000 | 20,500 | 23,000 | 26,000 |
| 4/0 to 1 B. & S. | | | 11,000 | 12,000 | 13,000 | 14,000 | 17,000 | 19,000 | 21,000 | 24,000 |
| 2 to 4 B. & S. | | | 10,000 | 11,500 | 12,500 | 13,500 | 16,000 | 18,000 | 20,000 | 22,000 |
| 6 B. & S. | | 8,000 | 9,500 | 11,000 | 12,000 | 13,000 | 15,000 | 17,000 | 19,000 | 21,000 |
| 8 " | 6,000 | 7,500 | 9,000 | 10,000 | 11,000 | 12,000 | 14,000 | 15,500 | | |
| 10 " | 6,000 | 7,500 | 8,000 | 9,500 | 10,000 | 11,000 | 12,500 | 13,500 | | |
| 12 " | 5,500 | 6,500 | 7,500 | 8,500 | 9,000 | 10,000 | 11,000 | 12,000 | | |
| 14 " | 5,000 | 6,000 | 7,000 | 7,500 | 8,000 | 9,000 | 10,000 | 11,000 | | |

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the other hand, is the specification as called for by a purchaser for the cables listed in Table III. It will be seen that the testing pressure recommended is from $1\frac{1}{2}$ to $2\frac{1}{2}$ times that called for by the purchaser. As far as working pressure is concerned, the factor of safety demanded by the purchaser in Table IV is, without doubt, sufficient. Yet the tests called for by this table would not begin to show up any but the most serious defects in the insulation of the respective cables.

The *A. R. E. E. committee on " Wire and Cable Specifications " has taken the most important step thus far in the standardization of voltage tests for cables, in its recent recommendations for tests on rubber, cambric and paper insulation.

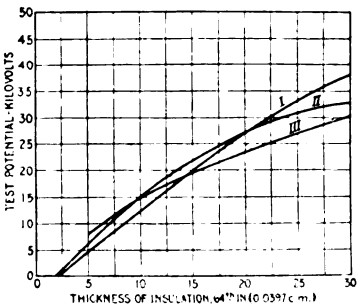


FIG. 4—POTENTIAL TESTS ON CONDUCTORS, RECOMMENDED BY A. R. E. E. No. 1 TO No. 4/0 A. W. G.

I. Paper or varnished cambric.
II. Rubber.
III. 155 $d \log_{10} D/d$ for No. 1 A.W.G.

From Fig. 3 it will be noted that there is but a relatively small difference in the values of $d \log_{10} \frac{D}{d}$ for diameters corresponding to No. 1 and No. 4/0 B. & S. gage, consequently one set of values covering these ranges has been recommended, and is plotted in Fig. 4.

Curve I is recommended for paper and varnished cambric, curve II for rubber, and curve III is the value of $Kd \log_{10} \frac{D}{d}$ when $K = 155$ and $d$ and $D$ are given in mils. Up to a 20/64-in. (7.95-mm.) wall the paper and cambric are rated at a lower working pressure than the rubber, for mechanical reasons, but above this they should test even better than the rubber.

## OVER-STRESSING CABLES

Much has been said in the past relative to unduly severe testing conditions in that the insulation, initially sound mechanically, becomes stressed beyond the electric elastic limit when tested. Although the short duration of the test may not develop any faults, the cable is nevertheless permanently injured, hence less able to withstand the shocks incidental to service conditions. This may be the case, but fortunately the insulation resistance

*Association of Railway Electrical Engineers

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TABLE III

RECOMMENDED VOLTAGE TESTS FOR LOW-VOLTAGE CABLES.

INSULATED WITH LOW-TENSION RUBBER COMPOUND. VOLTAGE TEST AT FACTORY FIVE MINUTES AS PER TABLE; VOLTAGE TEST AFTER INSTALLATION 30 MINUTES AT 50 PER CENT OF TABLE VALUE.

| Size conductor | Minimum thickness insulation, inches. | Test pressure, volts. |
|---|---|---|
| Stranded | | |
| 1,000,000 cir. mils. | 4/32 | 10,000 |
| 750,000 " | 4/32 | 10,000 |
| 500,000 " | 4/32 | 9,000 |
| 350,000 " | 4/32 | 9,000 |
| 4/0 A. W. G. | 3/32 | 7,000 |
| 2/0 " | 3/32 | 6,500 |
| 1/0 " | 3/32 | 6,500 |
| 2 " | 3/32 | 6,000 |
| Solid | | |
| 4 A. W. G. | 3/32 | 5,500 |
| 6 " | 3/32 | 5,500 |
| 8 " | 3/32 | 5,000 |
| 10 " | 3/32 | 4,500 |
| 12 " | 3/32 | 4,000 |
| 14 " | 5/64 | 3,500 |
| 14 (3) " conductor | 5/64 | 3,500 |

TABLE IV

VOLTAGE TESTS AS SPECIFIED BY A PURCHASER.

TESTS ON CABLES INSULATED WITH LOW-TENSION RUBBER COMPOUND. VOLTAGE TEST AT FACTORY FIVE MINUTES AS PER TABLE; VOLTAGE TEST AFTER INSTALLATION 30 MINUTES AT 50 PER CENT OF TABLE VALUE

| Size | Strds. | Wall. | Volts working pressure | Volts test pressure |
|---|---|---|---|---|
| Stranded | | | | |
| 1,000,000 cir. mils. | 61 | 4/32 | 1000 | 4000 |
| 750,000 " | 61 | 4/32 | " | 4000 |
| 500,000 " | 37 | 4/32 | " | 4000 |
| 350,000 " | 37 | 4/32 | " | 3000 |
| 4/0 A. W. G. | 19 | 3/32 | " | 3000 |
| 2/0 " | 19 | 3/32 | " | 3000 |
| 1/0 " | 19 | 3/32 | " | 3000 |
| 2 " | 7 | 3/32 | " | 3000 |
| Solid | | | | |
| 4 A. W G. | | 3/32 | 1000 | 3000 |
| 6 " | | 3/32 | " | 3000 |
| 8 " | | 3/32 | " | 3000 |
| 10 " | | 3/32 | " | 3000 |
| 12 " | | 3/32 | " | 3000 |
| 14 " | | 5/64 | " | 2000 |
| 14 " | 3-Cond. | 5/64 (no belt) | " | 2000 |

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and the electrostatic capacity enable us to determine the degree to which the insulation has been over-stressed.

Immediately after the stress is applied, the insulation resistance, measured with direct current, may drop considerably below its initial value as obtained a few moments previous to the application of voltage. This change may be as great as 50 per cent. If further readings of insulation resistance are taken, they will show a gradual increase and will approach their initial value

TABLE V

WIRES SHOWING RESULTS OF STRESS.

Megohms in 1000 ft.

| Test No. | Feet | Before voltage | 2500 volts 1 min. | 5000 volts 1 min. | After 2 hours | 5000 volts 5 min. | After 2 hours | |
|---|---|---|---|---|---|---|---|---|
| 1 | 1562 | 14,500 | 14,500 | 7,500 | 11,500 | | | |
| 2 | 1547 | 22,000 | 22,000 | 16,000 | 18,000 | | | |
| 3 | 3150 | 7,500 | 7,500 | 6,000 | 7,000 | 5,000 | 5,000 | |
| 4 | 1740 | 15,000 | 15,000 | 6,500 | 10,000 | 750 | 2,500 | |
| 5 | 2402 | 15,000 | 15,000 | 7,500 | 10,000 | 2,500 | 3,500 | |
| | | | | | | | Break-down, voltage | Megohms in 1000 ft. after repair. 4000 volts, one min. |
| 6 | 3560 | 4,800 | | | | 4,620 | 13,000 | 4,400 |
| 7 | 1425 | 3,500 | | | | 3,440 | 12,000 | 4,470 |
| 8 | 2350 | 9,000 | | | | 9,015 | 15,000 | 8,425 |
| 9 | 2750 | 7,660 | | | | 7,660 | 15,000 | 9,150 |
| 10 | 2400 | 2,950 | | | | 2,740 | 7,500 | 2,810 |

if the cable has not been over-stressed, whereas, if it has been over-stressed, the resistance recovers but little. Care must be taken to keep the temperature constant during these tests, for insulation has a very large resistance temperature coefficient. Table V shows some typical data taken from tests made on long lengths of wire as they were passing through the testing room.

The insulation resistances in tests (1) and (2) were affected considerably after the 5000-volt one-minute test, but practically recovered after two hours. It is possible that they would have

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completely regained their initial resistance if allowed sufficient time.

Tests (3), (4) and (5) were first made under the same conditions and, except in the case of (3), the recovery was much poorer than in the former cases. They were then subjected to 5000 volts for five minutes, with a noticeable reduction in the resistances of (3) and a very large and permanent reduction in that of (4) and (5). These last two were permanently injured.

In tests (6) to (10) inclusive, there was no marked decrease in resistance after the 5000-volt test, so they were broken down, repaired by patching the faults, tested at 4000 volts for one minute, and the insulation resistance measured again, with the results shown in the table. Tests (7) and (9) gave even better

TABLE VI

WIRES SHOWING THE RESULTS OF STRESS.

Microfarads per 1000 ft.

| Feet | Before voltage test | After 5000 volts for 1 min. |
|---|---|---|
| 3150 | 0.126 | 0.130 |
| 2176 | 0.146 | 0.150 |
| 2470 | 0.130 | 0.134 |
| 2925 | 0.130 | 0.133 |
| 2775 | 0.120 | 0.124 |

results than the initial resistances, due no doubt to patching a localized fault.

Unfortunately, the electrostatic capacity of these cables was not measured after every application of voltage, but Table VI shows in a general way the increase of capacity due to stress in the dielectric. For a given stress the change in capacity is much smaller than the change in resistance.

These results show that it is possible to make a rubber compound which is not easily stressed, beyond the electric elastic limit, and further, that if a compound is so stressed it is possible by means of the insulation resistance to determine if the test has been too severe.

## FACTOR OF SAFETY

It is not the intention of the writers to tell the operating engineers what should be the factor of safety in a cable system. Great fear has been expressed now and then, that engineers, knowing

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that cables will stand these high-voltage tests, will be tempted to use them on higher working pressures than they should. In this connection it is well to bear in mind that a factor of $2\frac{1}{2}$ times the working pressure is not applicable to all conditions.

(1) *In two systems of the same kilowatt capacity the cables on that system having the lower voltage should have the greater factor of safety.* This is because the surge voltage on the lower-voltage system will be greater because of the greater current, and the maximum possible rise in voltage is $e = i\sqrt{\frac{L}{C}}$, where $i$ is the amperes current transient, and $L$ and $C$ the system inductance and capacity, expressed in henrys and farads respectively.

(2) *In two systems having the same voltage, those cables operating on the system having the greater kilowatt capacity should have the greater factor of safety.* The reason for this is obvious. As has been frequently observed, transients that are practically unimportant in a small system become dangerous if allowed to take place in a large system. The writers have in mind a case where 2300-volt distributing cables, when connected to a relatively small plant, gave practically no trouble, but later, when this smaller system received its energy from a large transmission network, these same cables, though *normally* operating at the same voltage as before, gave so much trouble that they had to be replaced by cables better suited to the conditions.

## Method of Testing

The voltage test can be applied to wires and cables in several different ways; by submerging the cables in water; testing them against a metallic covering on the outside such as a lead sheath or tin foil; and testing one wire against another when there is more than one wire in the cable. The submersion test is the most severe as the water makes very close contact with the outside of the cable regardless of any surface irregularities that may be present. The water also has a tendency to penetrate into any foreign substance that may be in the insulating material, provided this substance has any affinity for water.

All of these tests may be, and generally are, made on rubber insulated cables. The cambric cables to be braided are generally submerged before and after braiding; cambric cables to be lead-covered are not submerged, as considerable trouble in drying them is experienced, and as they are to be tested after the lead

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covering has been applied, the submersion test is not necessary. Paper cables are not submerged, and all tests are made after leading.

The voltage test, as applied to cables, is practically the same whether it is made submerged against the lead, or against the contiguous wires, the object being to break down any weakness that may exist in the insulation. How much pressure, and for how long it shall be applied, are questions that have long been the subject of much discussion.

For several reasons, it is necessary to apply the voltage test to the finished cable and not to a short sample. (1) It is desirable to break down any weak places that may occur in the cable, it being quite impossible to avoid entirely such places in manufacture; (2) to satisfy inspectors and purchasers that the cable meets specifications as regards dielectric strength; (3) to obtain data and information as to the dielectric strength of the material; (4) constants obtained in laboratories from tests of short lengths are not applicable to commercial lengths and are usually misleading.

## Testing Apparatus*

Recommendations have appeared at different times regarding the type of generator and transformer that it is advisable to use for testing purposes, and the consensus of opinion seems to be that a smooth-core generator with field control, and a variable-ratio transformer, are most satisfactory. As will be shown later, it is doubtful if the generator of ordinary design can maintain its wave form under the severe conditions imposed by cable testing.

Where cables of some length are to be tested, a frequency of 25 cycles is preferable to one of 60 cycles, for the necessary generator and transformer capacities are practically proportional to the frequency, and according to the best information the writers can obtain there is no appreciable difference in severity of cable tests whether made at 25 or 60 cycles.

In the following tests, made in the testing laboratory of a wire manufacturer, the generator used was a motor-driven 25-kv-a., 220-volt, four-pole, 25-cycle, single-phase alternator, having 10 slots per pole, and a conductor belt $\frac{5}{8}$ the pole pitch. The transformer capacity was 50 kv-a., 220-50,000 volts. The secondary consisted of four separate 12,500-volt coils, capable of being con-

**High-Tension Testing of Insulating Materials*, A. B. Hendricks, Trans. A. I. E. E., Vol. XXX, part I, page 167.

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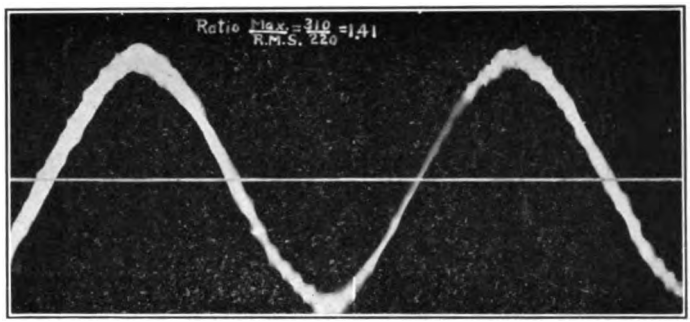


FIG. 5 [MIDDLETON AND DAWES]

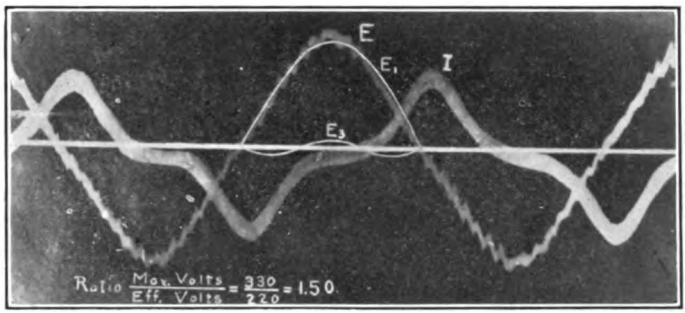


FIG. 6 [MIDDLETON AND DAWES]

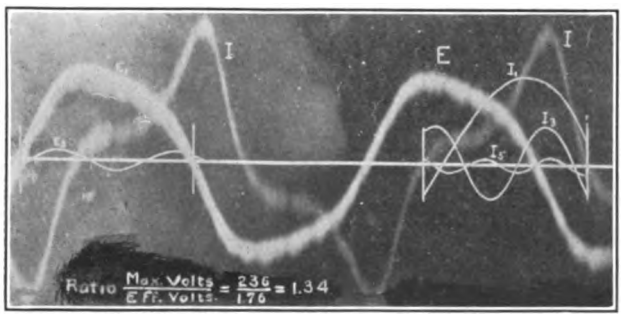


FIG. 7 [MIDDLETON AND DAWES]

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nected either in parallel, in series-parallel, or in series. The high-tension winding had a total of 12,512 turns, and the low-tension 55 turns. The reactance voltage was about 6 per cent.

Fig. 5 shows the generator voltage on open circuit, and except for the tooth harmonics, the e.m.f. wave is practically sinusoidal. For testing purposes, this wave is perfectly satisfactory if it could be maintained under all load conditions. In Fig. 6 is shown the generator voltage wave taken at 220 volts when the transformer is connected, and also the exciting current wave of the transformer.

This transformer exciting current is about 17 per cent of the rated load current of the transformer, but is 34 per cent of the rated load current of the generator. This is rather high, and further, Fig. 6 and other experiments showed that the transformer iron was being operated at unusually high saturation. It might well be argued that a large transformer magnetizing current is desirable, as it tends to offset the leading component of cable charging current, but it should be remembered that beyond a certain core density the additional exciting current is made up almost entirely of harmonics which do not neutralize the fundamental. Experience has shown this to be undesirable for other reasons. Examination of the current wave in Fig. 6 shows that the transformer takes a pronounced third harmonic current, and this current reacting on the generator flux tends to start wave distortion, producing a third harmonic in the e.m.f. wave as shown. If a cable, like most other electrical apparatus, took a comparatively small charging current, most of the following difficulties, due to wave distortion, would disappear.

Figs. 7, 8 and 9 show various voltage waves actually obtained under different conditions of test. The voltages on the cables, given in connection with all the following oscillograms are according to the ratio of transformation, hence, are not strictly correct. In actual practise this voltage is determined directly from the high tension side by means of a potential transformer.

The reasons for this distortion are obvious. The generator may have, inherently, a sine wave voltage, but the transformer exciting current has a prominent third harmonic. This current and the single-phase pulsating armature reaction produced on the flux wave, will usually introduce harmonics in the voltage wave as shown in Fig. 6. This wave is communicated to the transformer secondary where the cable intensifies it in its charging current, and it is reflected back in the generator current, and increased

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wave distortion results. These reactions are cumulative and will continue to increase until counter-reactions, set up in the magnetic and electric circuits become sufficiently great to balance them. Generator saturation, generator and transformer series leakage reactance and the phase relations of the harmonics may tend to counteract distortion. The value of series reactance may

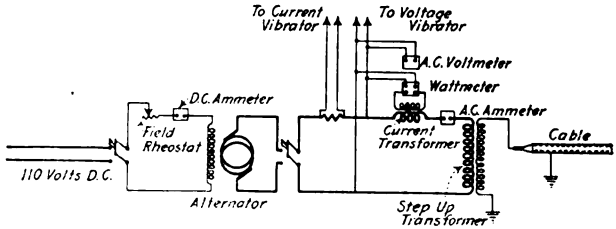


FIG. 10—DIAGRAM OF CONNECTIONS

be such as to produce resonance for one harmonic and not the others.

The generator may be represented by a coil that is a source of voltage and having reactance and resistance; the transformer may be replaced by a shunt impedance, of a value equal to the open-circuit impedance of the transformer, and by two series impedances, one representing the equivalent resistance and leak-

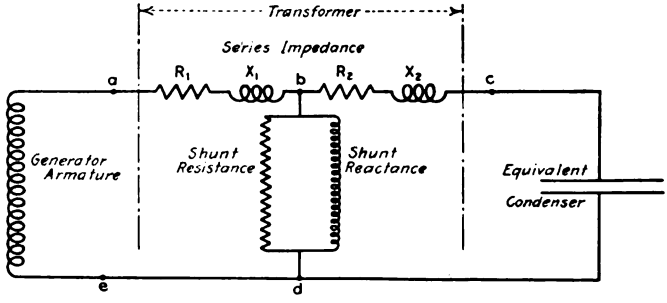


FIG. 11—EQUIVALENT CIRCUIT DIAGRAM

age reactance of the primary side, and the other the impedance of the secondary reduced to the primary side; the cable represents a condenser referred to the primary side and having a very high effective resistance. Fig. 11 shows this condition.

The shunt impedance *b d* has a decided effect on the generator wave form, in that its current wave, especially at the higher voltages, is mostly made up of harmonics, and these, reacting on the

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generator flux, are responsible for the initial distortion to which reference has been already made. The series circuit *a b c d e*, consisting of the transformer primary and secondary resistances and leakage reactances and the condenser, all in series with the generator armature, exerts some influence on the generator wave form. The magnitude and shape of the generator current wave, may be dependent on the relation of inductance to capacity in this circuit. Therefore, harmonics may be intensified or diminished depending on their frequency, on the transformer inductance and the cable capacity. These effects are illustrated in Figs. 12 to 15 inclusive.

The oscillograms shown in Figs. 12 and 13 were taken when a cable having a capacity of 0.1 microfarad was connected to the transformer secondary, and those shown in Figs. 14 and 15 were taken with another cable having a capacity of 0.13 microfarad, connected to the transformer secondary. Two tests were made with each cable; one in which all four of the transformer secondary coils were connected is series (50,000-volt) connection, the other in which the series-parallel (25,000-volt) connection was used. In order to compensate for the change in transformer ratio so that the effective voltage on the cable should remain approximately unchanged, the generator voltage was practically doubled when the change was made from the 50,000-volt to the 25,000-volt connection.

Figs. 12 and 14 show the results obtained with the 50,000-volt connection, and in each case the e.m.f. wave is very nearly sinusoidal, and no appreciable harmonics above the third, appear in the current wave. In each of these cases the generator was operated at low saturation, a condition in which it would be less able successfully to oppose severe reactions on the flux wave. The natural frequency of the transformer and cable circuit in the case of Fig. 12 is 110 cycles, and of Fig. 14, 96.6 cycles. The shunt circuit *b d*, owing to the variable nature of its inductance, would be difficult to take into consideration, except in a very general way and was consequently neglected in this frequency determination.

In Figs. 13 and 15, the approximate sinusoidal e.m.f. waves shown in Figs. 12 and 14 are distorted, containing fair-size fifth harmonics, and third harmonics about 50 per cent of the fundamental. In each case the current wave is even more distorted than the e.m.f. wave showing a seventh harmonic, a fifth equal in magnitude to the fundamental and a third about twice as

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great as the fundamental. In these cases, the natural frequency of the circuit was 215 and 192 cycles respectively.

Thus in each case, with the same generator, the same transformer, the same frequency and the same cable, an approximate sine wave is converted into a complex wave by simply changing the transformer ratio and the generator voltage. These phenomena cannot be explained on the basis of a resonant series circuit for the best wave shapes were obtained when the circuit constants were more conducive to the flow of the troublesome third and fifth harmonics. However, in these two latter cases the transformer exciting current contains harmonics of very appreciable magnitude as shown in Fig. 6, and in the writers' opinion, these harmonics are practically responsible for the results that were obtained.

It might also be added, referring to Fig. 11, that in the circuit *a b c d*, the resistance is very small, thus offering excellent opportunities for oscillations to take place during the transient or building up condition. Great care must be exercised in raising and lowering the voltage, as the possibility of building up an abnormal potential across the cable is always present, and this may result in a puncture.

Specific illustrations of this have come to the writers' attention on several occasions. When the voltage across a cable was being gradually raised, the spark-gap, connected in parallel, would discharge light sparks, momentarily, when the switchboard voltmeter indicated that the potential across the gap was only half that at which the gap was set. If the voltage was held constant for an instant, the sparking would discontinue, and the voltage could then be raised cautiously without further disturbance. The fact that the gap was not ruptured showed that a transient rise of voltage occurred, but that there was insufficient energy to cause a dynamic arc.

## Use of Reactance

It occurred to the writers that the generator current might be considerably reduced by using a shunt reactance to neutralize the leading component of the cable-charging current, thus securing a better wave form by reducing the ampere load on the generator. This has been tried abroad* and also by the Edison Electric Illuminating Co. of Boston.†

**Electrotechnischer Zeitschrift*, Feb. 27, 1908.

†"High-Potential Cable Testing at Boston," by C. L. Kasson, *Electrical World*, Vol. 60, p. 354.

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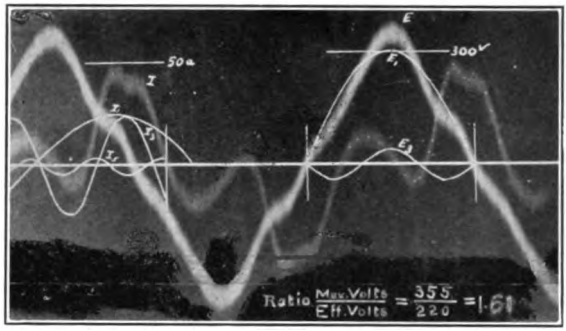


FIG 8 [MIDDLETON AND DAWES]

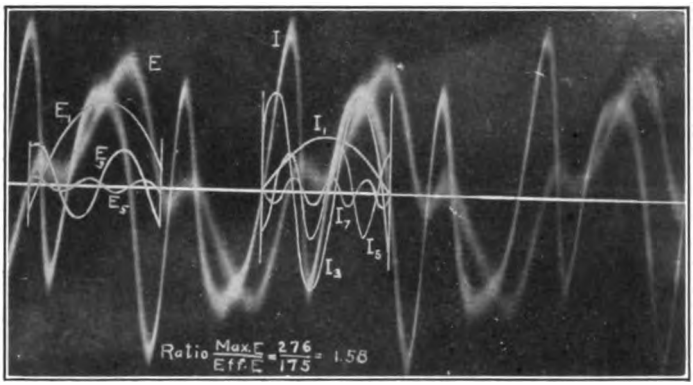


FIG 9 [MIDDLETON AND DAWES]

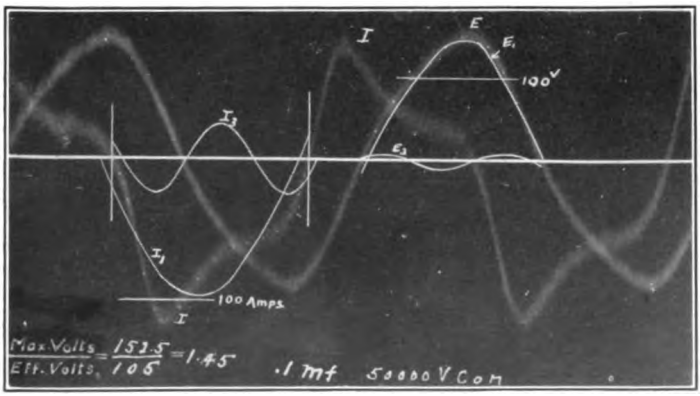


FIG 12 [MIDDLETON AND DAWES]

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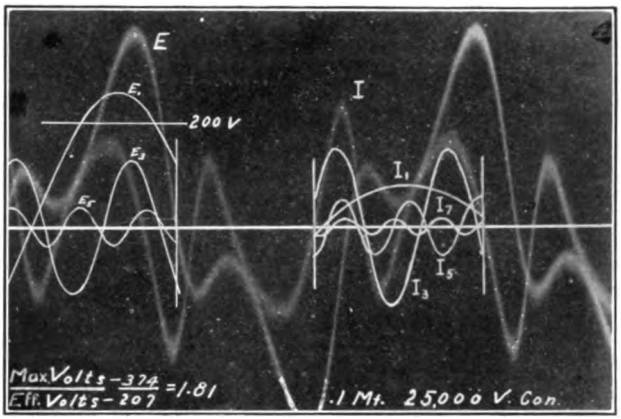


FIG. 13 [MIDDLETON AND DAWES]

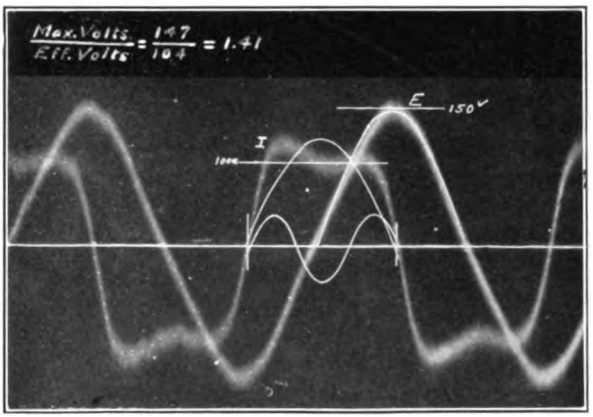


FIG. 14 [MIDDLETON AND DAWES]

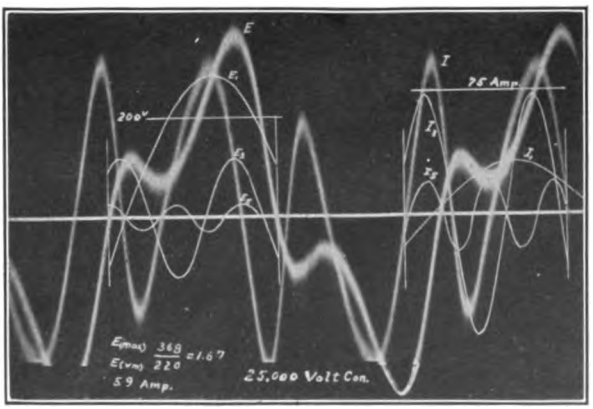


FIG. 15 [MIDDLETON AND DAWES]

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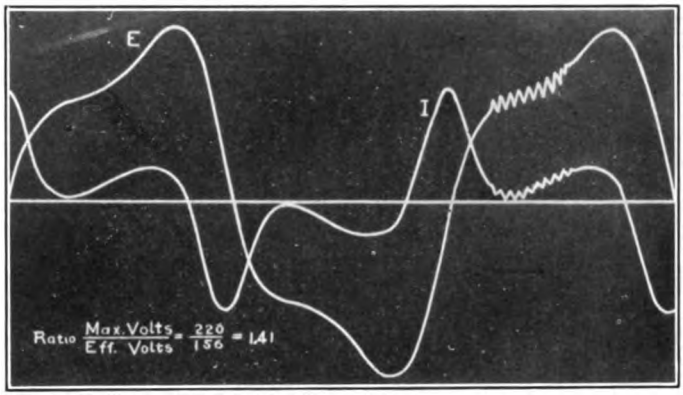


FIG. 16 A [MIDDLETON AND DAWES]

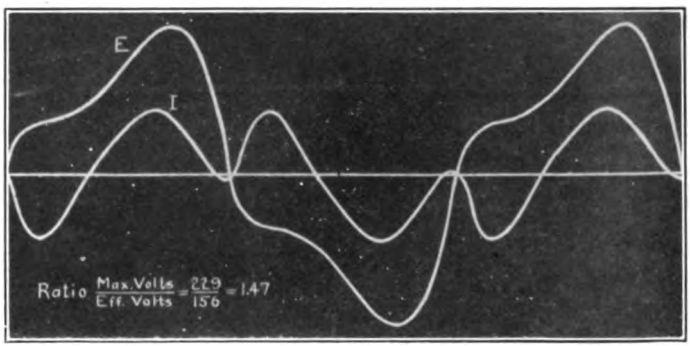


FIG. 16 B [MIDDLETON AND DAWES]

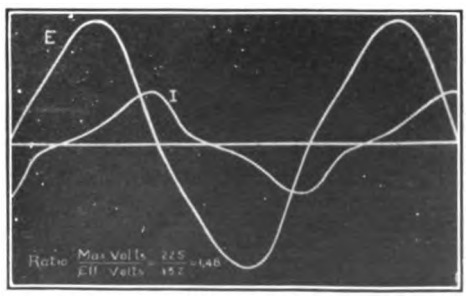


FIG. 16 C [MIDDLETON AND DAWES]

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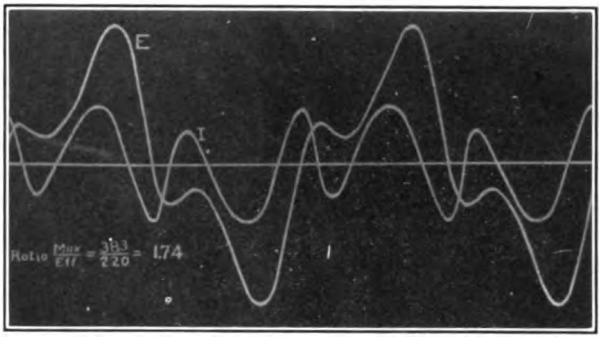


FIG. 17A [MIDDLETON AND DAWES]

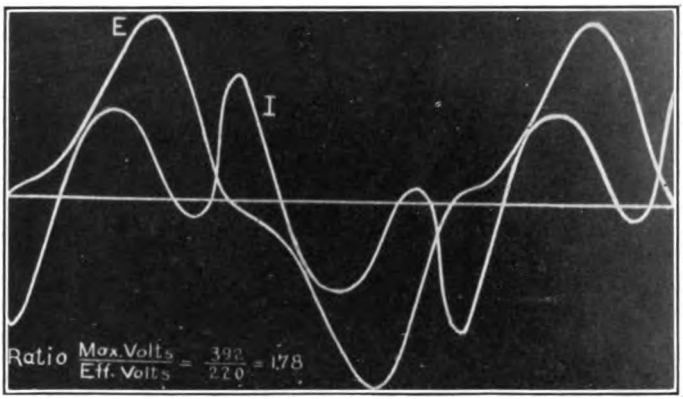


FIG. 17B [MIDDLETON AND DAWES]

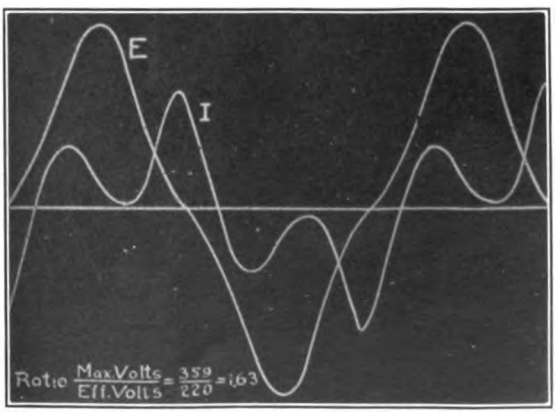


FIG. 17C. [MIDDLETON AND DAWES]

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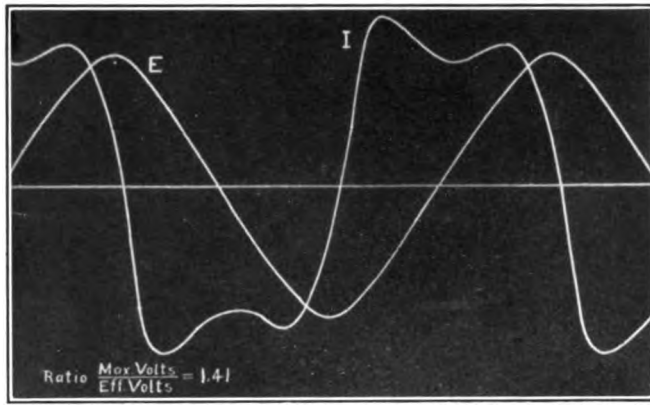


FIG. 18A [MIDDLETON AND DAWES]

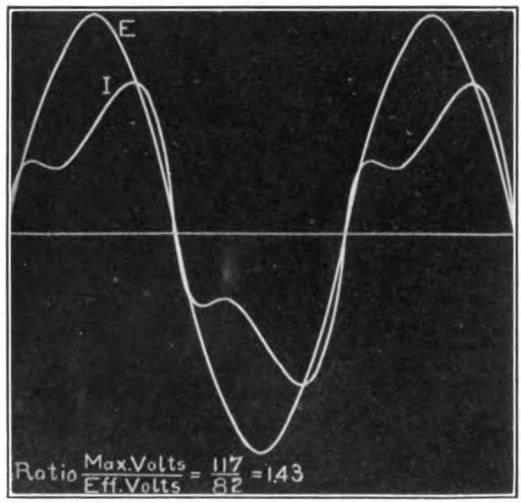


FIG. 18B [MIDDLETON AND DAWES]

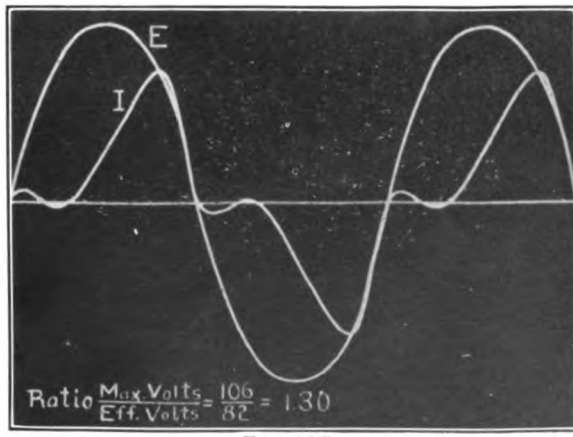


FIG. 18C. [MIDDLETON AND DAWES]

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We made nine tests, and in every case the same cable was used, namely 1000 ft. (305 m.) No. 1/0, 7/32 in. (5.56 mm.) wall, rubber insulation, having a capacity of 0.175 microfarad. Three different tests were made at each of three different voltages. At each voltage; first, the oscillogram was taken without the reactance; second, the reactance was adjusted until the line current was a minimum; and third, the reactance was adjusted for the best voltage wave form. The results of these tests are shown in Figs. 16A to 18C inclusive.

The following conclusions are to be drawn from the above tests.

(1) The point of minimum current does not necessarily correspond to the best wave shape.

(2) The best wave shape may occur at an abnormally large value of lagging current.

(3) The wave can not be made sinusoidal in every case.

(4) At the point of minimum current (usually denoting resonance for a parallel circuit) the power factor is below 50 per cent in two cases, and 70 per cent in the third, and the waves are not necessarily in phase.

Further, in Figs. 18A, 18B and 18C, when the generator voltage was low, there was but slight distortion in the e.m.f. wave, which tends to confirm the previous theories as to the effect of the transformer exciting current on the e.m.f. wave.

Thus with a commercial generator and transformer, the e.m.f. wave, by the use of reactance, could not always be made sinusoidal, and when this was accomplished, it was at the expense of greater generator capacity. This is undoubtedly due to the fact that a circuit can be tuned to but one frequency at a time, and when the third harmonic current was neutralized, the reactance allowed a very large fundamental to pass. The power-factor is explained by the fact that the harmonic currents in cable tests predominate in the current wave, whereas the voltage is largely fundamental. The harmonics in the current wave contribute no power with respect to the fundamental voltage, yet all add up in quadrature, contributing to the volt-amperes.

These results show that in our particular case, at least, a shunt reactance would be of but very little value in improving the generator wave form, and reducing the volt-ampere load of the generator.

## Sine-Wave Generator

As a result of our tests, the wire manufacturer came to the conclusion that a generator of the ordinary design was wholly un-

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suited for reliable testing of wires and cables. Moreover, no manufacturer would guarantee a generator to produce an approximate sine wave under these severe conditions of test. The services of Prof. C. A. Adams of Harvard University were secured, and under his specifications such a generator was built and installed, rated at 85 kv-a. All oscillograph records, taken up to the present time and under various conditions of test, have failed to show any departure from a sine wave.

The 50-kv-a. transformer has been replaced by one rated at 75 kv-a., 75,000 volts, operating at a much lower core-density than the former, and taking a much less distorted exciting current. Hence the distorting influence of this current on the generator wave is much less than it was in the case of the 50-kv-a. transformer.

## Method of Measuring Voltage

It is essential to obtain reliable knowledge of the maximum voltage to which the cable may be stressed under the preceding conditions of distorted wave form, if the tests are to be of any great value. Where the wave varies from a peaked to a flat-topped wave, the effective value is only a poor indication of what the maximum voltage may be. The circuit conditions are a function of so many variables that only a wide experience with his apparatus enables an operator to know what wave form may be expected under any given set of conditions.

The spark gap immediately suggests itself, as a means of determining these peak values. Although the needle gap is not conceded to be a device of high accuracy yet it is accurate enough for the work in hand. There are objections to its use, however. The voltage can only be determined by connecting the gap in parallel with the cable to be tested, and noting the transformer primary voltage when the gap breaks down at the predetermined value at which it is set. This is a very dangerous practise, as a disturbance is created in the highly oscillatory circuit already described, and cables have often been known to puncture at a voltage apparently much less than their rating, and after the gap had actually broken down. The spark gap can therefore be used only with considerable care, and the danger of a surge is always present. Furthermore, it is not a piece of apparatus that is easily or quickly manipulated, and is wholly unsuited for a testing room where a large number of tests must be completed in a short time.

The oscillograph in its ordinary form is a very satisfactory

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piece of apparatus for experimental work, but it requires considerable attention, is clumsy to handle, requires skill to manipulate, and it does not hold its calibration for any considerable time.

Prof. F. A. Laws of the Massachusetts Institute of Technology, and the writers, have, however, adapted the oscillograph principle to an instrument which may be placed directly on the switchboard, and from which the peak value of any voltage wave may be quickly and accurately determined. A sectional view of this instrument is shown in Fig. 19, and is almost self-explanatory.

The lamp having a straight tungsten filament, is mounted so that its distance from the vibrator may be adjusted to suit the optical requirements of the system. The light then passes through

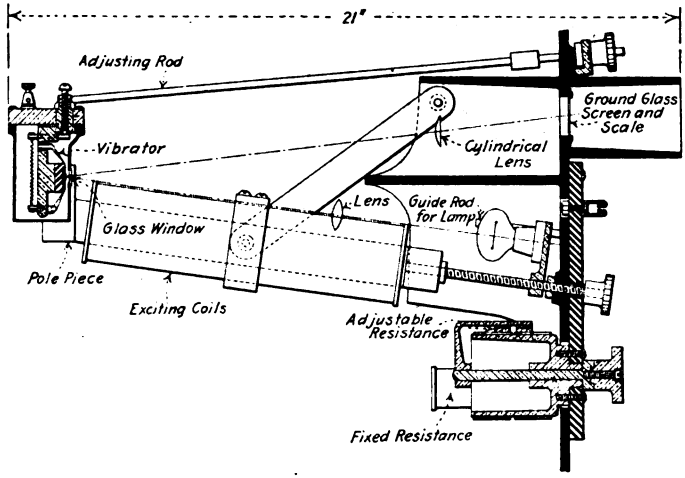


FIG. 19—SECTIONAL VIEW OF SIMPLEX VIBRATING VOLTMETER

suitable spherical lenses to the vibrator, from which it is reflected through a cylindrical lens to the ground glass screen, where the peak of the voltage wave may be determined from the extremity of the band of light.

The necessary vertical and horizontal adjustment of the beam of light can be made from the front of the switchboard by means of two milled heads which actuate the two adjusting rods. To compensate for changes in the amplitude of vibration due to variations of temperature and other causes, an adjustable rheostat is connected in series with the vibrator, and by throwing the vibrator circuit on direct current, with a double-throw switch, the calibration can be quickly and accurately made. A double scale is also provided. The magnets are operated at high satura-

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tion so that fluctuations in exciting current affect the instrument but slightly. The instrument as used, is connected to the secondary of a potential transformer, whose primary is connected directly to the high-tension circuit. Other views of the instrument are shown in Figs. 20 and 21.

To the manufacturer the importance of this type of instrument is evident. He is aware of the maximum stress at which his cables are being tested at all times, regardless of generator and transformer wave-form. No additional factor of safety is necessary in the cable due to uncertainty on this point. Furthermore, purchasers and inspectors can be quickly and convincingly shown that their cables are being tested at the specified voltage, without employing a troublesome oscillograph or a spark-gap, and without exposing the cable to the dangers accompanying the use of this latter device.

This instrument is not only useful for cable-testing, but can be employed to advantage where apparatus other than cables must undergo potential tests. The e.m.f. waves of all testing-generators are not sinusoidal, even at light loads, and their wave-form may change with the field excitation.

When the e.m.f. is taken directly from a commercial circuit supplying other loads, this voltage wave may vary with the load and the number of generators on the system, as well as through the compensators and other control devices employed.

This voltmeter is also capable of indicating slow-period transients which the ordinary type of meter owing to its inertia cannot follow. Instances of this have come to the writers' attention in the cases already cited, when the voltage was being raised on a cable. In a certain power system, it was found necessary to change the lightning arresters from 2300 to 3300 volts owing to the fact that continual discharges were taking place due to a considerable length of submarine cable having been added to the system. Whether this was due to a change in wave-form or to surges, the writers are not prepared to say, but such an instrument would have quickly given the required information.

In closing the writers wish to express their thanks to Prof. F. A. Laws, of the Massachusetts Institute of Technology, for his part in the developement of this instrument; to Mr. W. G. Wolfe, of Boston, for his assistance in developing the optical system; to Professors C. A. Adams, H. E. Clifford, and A. E. Kennelly of Harvard University, for their helpful suggestions and criticisms during the preparation of this paper.

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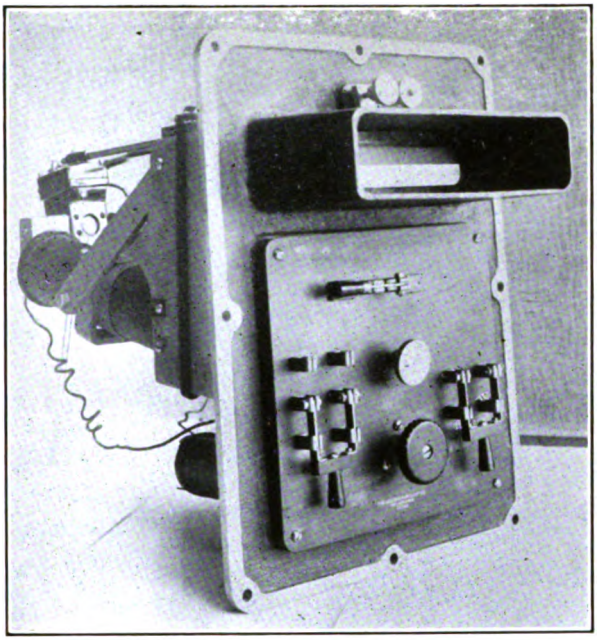

FIG. 20 [MIDDLETON AND DAWES]

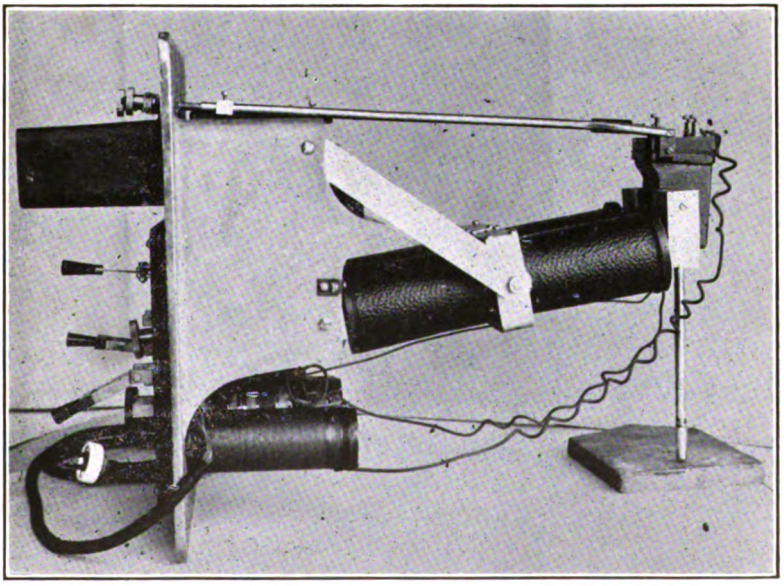

FIG. 21 [MIDDLETON AND DAWES]

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*Subject to final revision for the Transactions.)*

# DIRECT-CURRENT MOTORS FOR COAL AND ORE BRIDGES

BY R. H. McLAIN

ABSTRACT OF PAPER

This paper gives a brief description of the mechanical arrangement of a coal bridge. The bridge consists essentially of a trolley car with hoisting mechanism for a self-filling bucket. A series-wound motor is recommended for driving the trolley car; and the proper method of gearing the motor for the most economical results is discussed. A series-wound motor is recommended for a low-speed hoist and a shunt-wound motor for a high-speed hoist. The relative merits of the two methods of winding the motor are considered.

A MAN trolley type coal or ore bridge consists essentially of a trolley car on an elevated railway carrying a self-filling bucket, with machinery for hoisting, lowering, opening and closing the bucket. The name of this type of bridge comes from the fact that the operator rides in the car. The bucket is suspended on two ropes, a "closing line" and a "holding line." If the holding line is stationary, the bucket will close when the closing line is taken in and will open when the closing line is let out. The elevated track or bridge spans a storage pile and usually extends out over a slip of water to cover a boat and often extends over railroad tracks on the other end. The bridge is supported on rails and can move along the storage pile.

Either one motor or two motors, in parallel, are used for propelling the trolley car. Generally two motors are used—one at one end and one at the other end of the car—so as to get uniform weight distribution and maximum tractive effort from the car wheels. Two hoist drums are used, one for the closing line and one for the holding line. The closing line drum is geared directly to a motor, while the holding line drum may be either driven from the closing drum through a clutch or geared to a separate motor.

Sometimes it is deemed advisable to use two motors geared together, instead of one, so as to get mechanical advantages in the trolley, such as even distribution of weight, and so on. For pur-



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poses of this paper we will consider that one motor is used for propelling and that one motor does all of the hoisting. Where two motors are geared together and used as one, the characteristics are the same as if one motor were used, except that special precautions are taken in the design of the controllers to make the motors divide their loads properly.

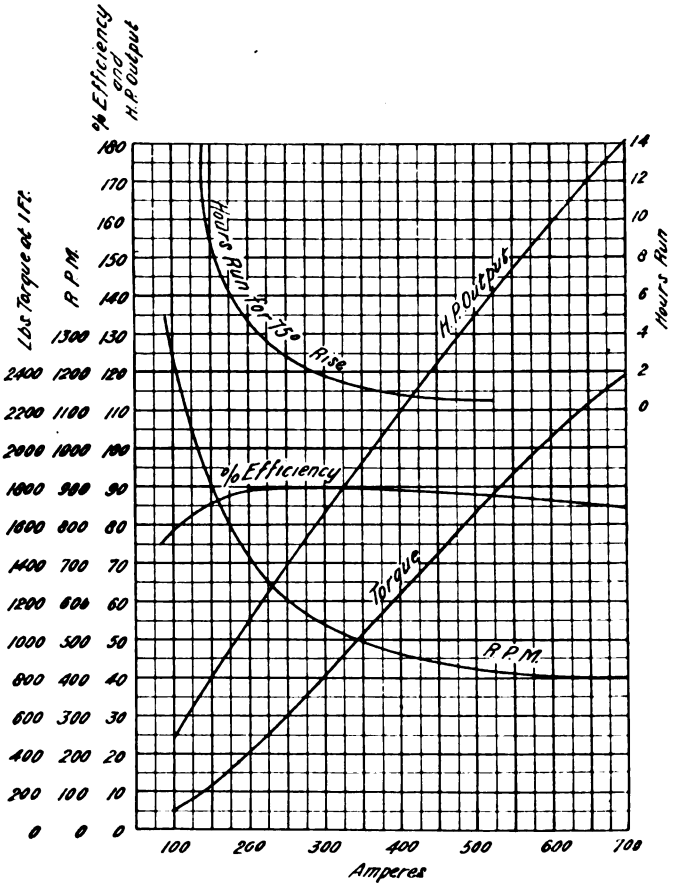


FIG. 1—SPEED-TORQUE-CURRENT CURVES OF A 100-H. P. SERIES-WOUND MOTOR

The problem for the propelling service is to move the car back and forth over the storage pile, making trips of various lengths, as quickly as possible. The distances vary from 50 to 600 ft. (15 to 180 m.), and the car speeds may reach a maximum of 1500 ft. (460 m.) per minute. A series-wound motor is well adapted for this service because it exerts about 50 per cent greater torque

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per ampere on starting than on running. This feature makes a considerable saving in power consumption and power peak, as well as in the size of the motor, because most of the work of this motor is the starting and stopping of the trolley. The usual acceleration for the trolley is 1.5 to 2.5 ft. (46 to 76 cm.) per second per second. The speed for which the trolley is geared to run after all accelerating is completed—the "free running speed"—should be determined from the distance to be traveled and the time allowed for making the trip. For short trips the free running speed should be low and the accelerating rate high; while for long trips the free running speed should be higher and the accelerating rate lower. On a given coal bridge the average

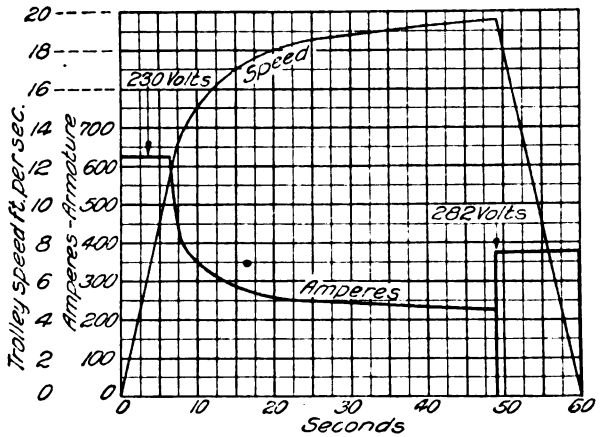


FIG. 2—SPEED-TIME AND CURRENT-TIME CURVES OF A 45-TON MAN TROLLEY, GEARED TO A 100-H. P. SERIES-WOUND MOTOR

Maximum speed of motor, 655 rev. per min.; maximum speed of trolley, 19.75 ft. per sec.

length of trip should determine the values to be used. In order to study the problem the writer has made up a number of curves showing the distance traveled in given times for various free running speeds and various rates of accelerating. These curves were made by plotting speed-time curves and integrating them to find the distance traveled.

Fig. 1 shows the speed-torque current curve of a series-wound motor. If this motor is geared to a trolley whose weight is 45 tons,* gear loss 10 per cent, rolling friction 35 lb. (16 kg.) per ton, free running speed 19.75 ft. (6.02 m.) per second, acceleration and retardation 1.8 ft. (55 cm.) per second per second, the speed-time curve will be as shown in Fig. 2. The area of this curve

*1 short ton = 0.90718 metric ton.

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represents the distance traveled by the trolley in 60 sec. Fig. 3 and 4 show the net results of a number of curves like Fig. 2. Fig. 3 shows feet traveled plotted against seconds for free running speeds between 7.5 ft. (2.3 m.) per sec. and 25 ft. (7.6 m.) per sec., acceleration and retardation being taken as 1.5 ft. (46 cm.) per sec. per sec. Fig. 4 is like Fig. 3, except that 2 ft. (61 cm.) per sec. per sec. is used.

It is interesting to note on Fig. 3 that if only 75 ft. (23 m.) is to

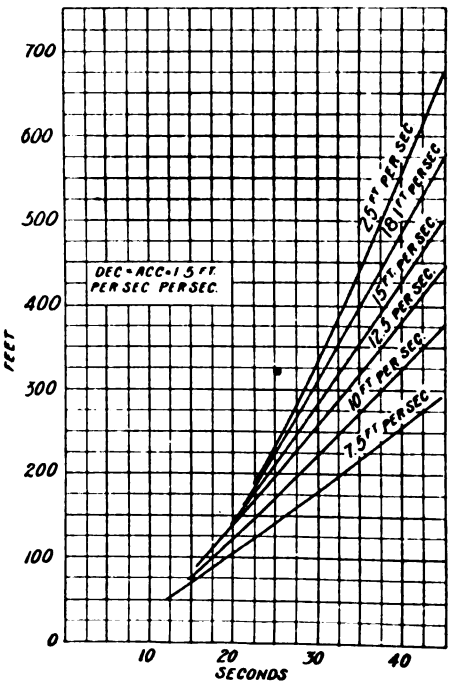


FIG. 3—DISTANCE-TIME CURVES FOR A 45-TON MAN TROLLEY GEARED TO A SERIES-WOUND MOTOR FOR "FREE RUNNING SPEEDS" VARYING FROM 7.5 TO 25 FT. PER SEC.

Acceleration equal to retardation equal to 1.5 ft. per sec. per sec.

be traveled it will take 14.5 sec. no matter whether the free running speed is more than 10 ft. (3.05 m.) per sec. or not. Consequently for 75-ft. (23-m.) trips there is no need of gearing for more than 10 ft. (3.05 m.) per sec. Likewise for a 150-ft. (46-m.) trip there is no need of gearing for more than 15 ft. (4.6 m.) per sec. It is easily understood that where low trolley speeds are used a given drawbar pull for accelerating can be obtained with the expenditure of less power than when high speeds are used.

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It is also interesting to note that if 225 ft. (68.5 m.) must be traveled in 25 sec. and an acceleration of 1.5 ft. (46 cm.) per sec. per sec. (Fig. 3) is used, the free running speed must be 18 ft. (5.5 m.) per sec.; while if 2 ft. (61 cm.) per sec. per sec. (Fig. 4) is used, the free running speed need be only 13 ft. (3.9 m.) per sec. For distances less than 225 ft. (68.5 m.) the first method of gearing would require more time per trip and for distances greater than 225 ft. less time.

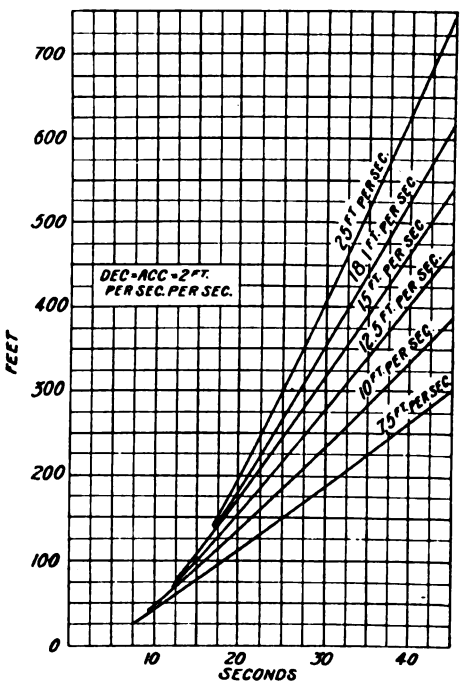


FIG. 4—DISTANCE-TIME CURVES FOR A 45-TON MAN TROLLEY GEARED TO A SERIES-WOUND MOTOR FOR "FREE RUNNING SPEEDS" VARYING FROM 7.5 TO 25 FT. PER SEC.

Acceleration equal to retardation equal to 2 ft. per sec. per sec.

For the control of a rack motor, simple rheostatic control of the automatic magnetic type should be used. On account of the large amount of kinetic energy to be dissipated when stopping the trolley it is advantageous to use the motor as a generator for stopping and thus save the maintenance of mechanical brakes. To obtain this braking the armature, series field and a rheostat should be connected in such relation that the field will build up the armature generate as shown in Fig. 5. The value of resis-

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tance should be such that at the maximum speed of the motor sufficient current and voltage will be generated to give the desired rate of braking. As the generator speed decreases the resistance should be decreased so as to maintain a uniform current and consequently uniform braking torque.

To determine the conditions of motor load let us take the case of the motor in Fig. 1 geared to the load described in Fig. 2.

Weight of load = 45 tons.

Rolling friction = 35 lb. (16 kg.) per ton when accelerating.

Gear loss = 10 per cent.

Motor so geared that 655 rev. per min. corresponds to 1185 ft. (361.2 m.) per min. or 19.75 ft. (6.02 m.) per sec.

Acceleration = retardation = 1.8 ft. (55 cm.) per sec. per sec.

Assume rolling friction 30 lb. (13.6 kg.) per ton when slowing down.

Assume gear loss 5 per cent when slowing down.

Pounds torque at one-ft. radius* required to accelerate the motor to 655 rev. per min. in 11 seconds = 74.5.

Then

$$\text{Drawbar pull to accelerate} = \frac{45 \times 2000 \times 1.8}{32.2} = 5040 \text{ lb.}$$

(2286 kg.).

Drawbar pull for rolling friction = $45 \times 35 = 1570$ lb. (712 kg.).

$$\text{Torque to accelerate load} = \frac{5040 \times 1185}{655 \times 2 \times \pi \times 0.90} = 1610$$

lb-ft.

$$\text{Torque to propel} = \frac{1570 \times 1185}{655 \times 2 \times \pi \times 0.90} = 500 \text{ lb-ft.}$$

Torque to accelerate armature = 74.5 lb-ft.

Total torque required while accelerating = 2184.5 lb-ft.

In Fig. 1, 2184.5 lb-ft. torque corresponds to 630 amperes. After all starting resistance is short-circuited and the motor is connected to 230-volt supply its speed will be (from Fig. 1) 405 rev. per min., which corresponds to 12.2 ft. (3.7 m.) per sec. Time required to attain this speed will be ($12.2 \div 1.8 =$) 6.8 sec. After this speed is attained the acceleration will be gradually reduced until uniform speed is attained. In Fig. 2 is plotted the current which corresponds to the speed and accelera-

*1 lb-ft. = 0.1383 kg-m.

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ting rate of the car. After 19.75 ft. (6.02 m.) per sec. is attained, (19.75 ÷ 1.8 =) 11 sec. will be required to stop.
Drawbar pull to retard =

$$\frac{45 \times 2000 \times 1.8}{32.2} = 5040 \text{ lb. } (2286 \text{ kg.}).$$

Drawbar pull for rolling friction = 45 × 30 = 1350 lb. (612 kg.)
Net required drawbar pull = 3690 lb. (1674 kg.)

Net torque corresponding =

$$\frac{3690 \times 1185 \times 0.95}{655 \times 2 \times \pi} = 1010 \text{ lb-ft.}$$

Torque to retard motor = 74.5 lb-ft.
Total torque to retard = 1084.5 lb-ft.

From Fig. 1, 1084.5 lb-ft. torque corresponds to 375 amperes and 500 rev. per min. If we assume that the motor has an internal resistance of 0.04 ohm its internal voltage with an excitation of 375 amperes at 500 rev. per min. will be 230 − (375 × 0.04) = 215 volts. At 655 rev. per min and 375 amperes the internal voltage will be approximately $\frac{655}{500} \times 215 = 282$ volts.

The resistance in series with the armature must therefore be 282 ÷ 375 − 0.04 = 0.715 ohm.

A series motor will build up as a generator when its field and armature are connected in the proper relation, but it takes several seconds for this to take place. Therefore it is advisable to excite the field separately with a small amount of current so as to hasten this action. Now, even with separate excitation, about one second more may elapse before full magnetic strength is attained. During this time there has been some braking action from the motor, so that by the time full magnetism is attained, the speed is less than 655 rev. per min. and the voltage never attains the value of 282 which was calculated.

When the time constants of the magnetic field and the absolute voltage and current capacity of a motor are well known it is possible to get results in braking which are far superior to the calculated conditions in Fig. 2. The retardation may be made much greater without overloading the motor in either current or voltage or kilowatt output. Fig. 5 shows the connections for a rack motor controller which gives power and dynamic braking in both directions of rotation. The resistance blocks

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must be proportioned not only for smooth accelerating but for retarding in the proper manner to suit the motor characteristics.

For hoist service we have the choice of series, compound or shunt-wound motors. The conditions which affect the choice are voltage variation, amount of power available, height of hoist and time required for the trip. A voltage variation of 10 to 20 per cent is usual. The power supply is generally limited, or at any rate peaks are penalized. The height of hoist in some locations is as low as 40 ft. (12 m.) and in others as high as 180 ft. (55 m.). Time allowed for the hoist may be anywhere from 6 to 15 sec.

The hoisting speed is of course fixed by the distance and time. Where a low speed is used the time of starting and stopping is unimportant, but for high speeds the time consumed in this way

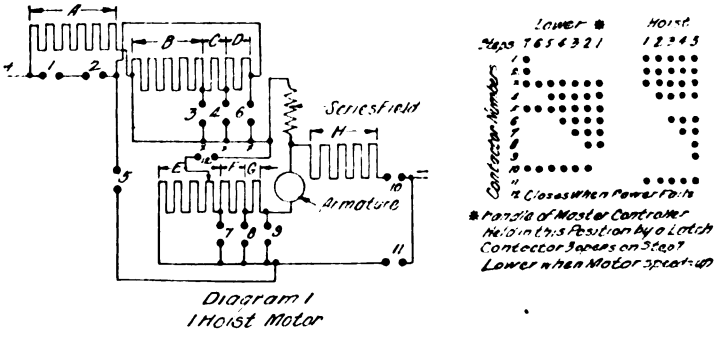


FIG. 5—CONTROLLER CONNECTIONS OF A SERIES-WOUND PROPELLING MOTOR ON A MAN TROLLEY COAL BRIDGE

is all-important. It is my opinion that a series-wound motor should be used for speeds of 360 ft. (110 m.) per min. or less if the height of hoist is such that at the speed used more than 8 sec. are consumed in the trip. For greater speeds and shorter time periods a compound-wound motor should be used. For still greater speeds of, say, 700 ft. (213 m.) per min. or more, a shunt-wound motor should be used. In order to present my ideas I will use two extreme examples.

Let us take a speed of 300 ft. (91.5 m.) per min., or 5 ft. (1.52 m.) per sec., a height of 40 ft. (12 m.) and a bucket which has 35 ft. (10.6 m.) of rope to be taken up while it is closing. It is possible on such a bucket to let the motor run at full speed while the bucket blades are in the act of coming together and the bucket is starting up; therefore no time is lost by running at re-

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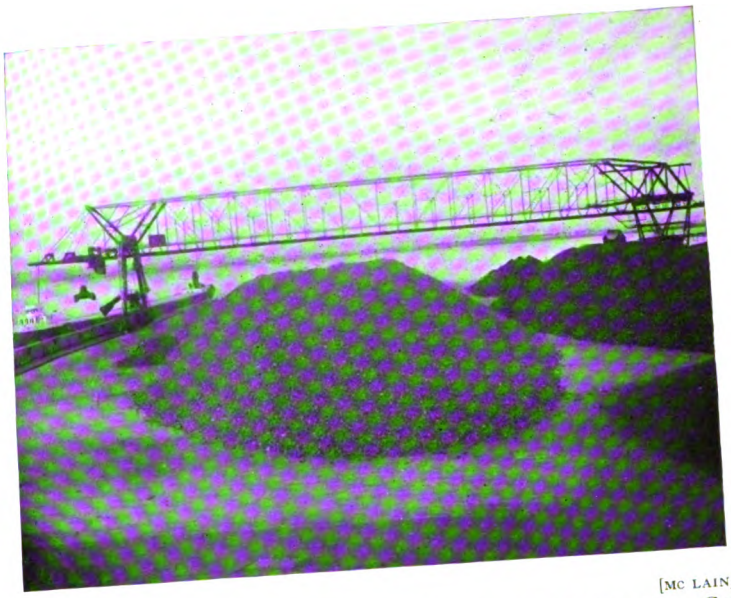

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FIG. 7—VIEW OF A MAN TROLLEY COAL BRIDGE SPANNING A COAL STORAGE PILE AND A BOAT

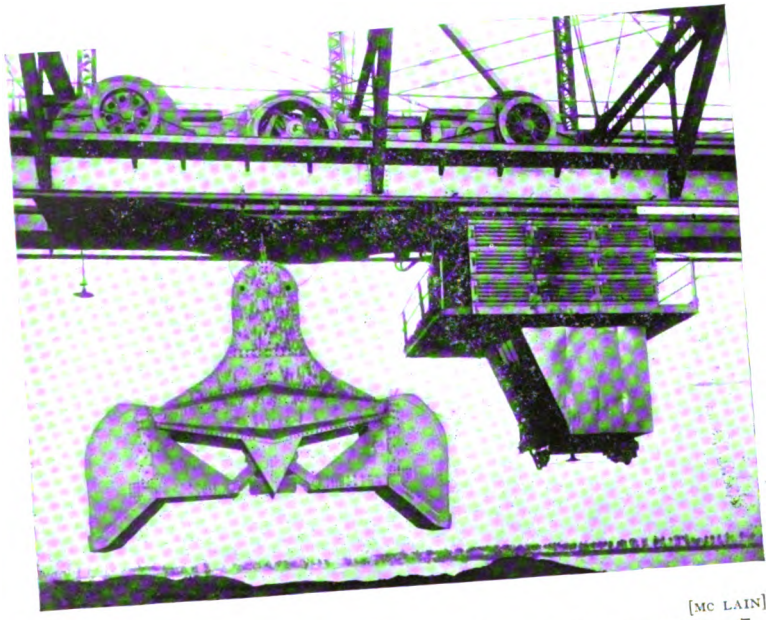

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FIG. 8—VIEW OF BUCKET AND TROLLEY USED ON BRIDGE IN FIG. 7.

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duced speed from the time the motor attains full speed in starting to close until the bucket is fully hoisted. If a shunt motor were used, 1.5 sec. would be required to start, 1 sec. to stop and 13.75 sec. would be required for full-speed running to wind up the whole seventy five ft. (22.8 m.) of rope. This makes a total of 16.25 sec. to make the trip. If a series motor were used, the same time would be required, except for the fact that while the bucket is being closed the load on the motor is small and the motor speeds up. The motor will run about 30 per cent above normal speed for most of the closing period, but toward the end of this period the load increases and the speed comes down to normal. About one second is saved by the series motor on each trip. Therefore the shunt motor would have to be geared for 6 per cent more speed in order to make the trip as quickly as the series motor, and would take 6 per cent more power while hoisting at full speed. Automatic current limit control is used on these motors; and since, at times, it is necessary to start the bucket from midair, the relays must be set for a current which will be great enough to start the loaded bucket even at the lowest line voltage. No more than this current is required, because the time of starting is unimportant. When a relay drops and a contactor short-circuits a block of resistance there is a consequent current peak. For a given number of contactors, the ratio of these current peaks to the current at which a relay drops is at least 10 per cent more for a shunt than for a series motor. Furthermore, the current at which a relay drops must be made greater on a shunt motor, because, on low voltage and consequently weakened field, more current is required for a given torque than is required on a series motor whose field strength is not affected by voltage variation. On 80 per cent of normal voltage the current in a shunt motor may increase as much as 10 or 20 per cent. Summing up the above statements, we see that the starting current on the shunt motor will be about ($1.06 \times 1.10 \times 1.15 =$) 1.34 times the starting current on a series motor. The series motor has the further advantage that when the bucket is not digging much coal and the weight is reduced, the speed will increase. Another advantage is that the series motor can stand the rapid voltage fluctuations with no damage, while a shunt motor may be damaged.

On high hoist speeds all of the advantages mentioned above for the series motor disappear, and a very decided advantage appears for the shunt motor. At these high speeds it is import-

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ant that the full hoisting speed be as nearly constant as possible, regardless of voltage or load. The speed of a series motor may vary at least 30 per cent more, under service conditions, than that of a shunt motor. If the speed is say, 15 ft. (4.57 m.) per sec., 30 per cent variation means 4.5 ft. (1.37 m.) per sec. An operator cannot be expected to hoist to the correct height under such conditions without wasting considerable time running at low speed just before stopping at the top. Another advantage of the shunt motor is that it is very easy and simple to provide dynamic braking for stopping at the top so that no time need be wasted in getting stopped.

Let us take the example of 900 ft. (274 m.) per min. or 15 ft. (4.57 m.) per sec. speed, and 90 ft. (27.4 m.) height. A shunt motor will close the bucket as quickly as a series motor because the bucket will not dig properly if either motor runs at full speed. It is necessary to slow down or stop just as the bucket blades close, because the speed is so high. In order to make it worth while to use such a high speed, not over 3 sec. can be allowed for accelerating. This means that a rate of 5 ft. (1.52 m.) per sec. per sec. is used for acceleration or an extra pull of 15.5 per cent on the bucket. About 15.5 per cent additional pull is required to accelerate the drums and gears. In most cases a torque equivalent to 50 per cent of the pull on the bucket is required to accelerate the motor armature. The total torque required for accelerating in 3 sec, and for hoisting is therefore 181 per cent of the torque required for hoisting alone. In order to accelerate so quickly the current relays must be set to drop down at 145 per cent of the hoisting current. This is so high above normal that even on 80 per cent voltage the motor will start and therefore no extra current peaks are encountered, as would be the case on a low-speed hoist. There would, however, be greater peaks of current caused by the short circuiting of the starting resistance, unless the field were made especially strong for starting and then reduced to normal strength during full speed running. An increase of speed due to a light load is a disadvantage on such a high speed because it deceives the operator and causes mistakes in the height to which the bucket is hoisted. A motor which has enough reserve capacity on its commutator to stand the 81 per cent overload encountered at starting will not be liable to much damage from fluctuating voltage, and therefore no extra cost need be put into the motor to make it stand this condition.

As mentioned above, it is advantageous to stop at the top with

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dynamic braking on a high-speed hoist. If the motor is geared directly to its load the combined motor and load, for the case of 900 ft. (274 m.) per min. speed above stated, would coast ($0.81 \times 3 =$) 2.43 sec. after power is shut off, and in this time would travel ($2.43 \times 15 \div 2 =$) 13.2 ft. (4 m.) One second of this time could be saved by waiting till the bucket is within 7.5 ft. (2.3 m.) of the top and then applying full capacity of the motor as a brake by connecting resistance in parallel with the armature. Such an arrangement has other practical advantages. For example, if the bucket is just starting out of a boat and is about to strike a hatch coaming, it is imperative that an easy means of making a quick stop be at hand.

It is common practise on low-speed hoists which use series motors to lower the empty bucket by dynamic braking. All

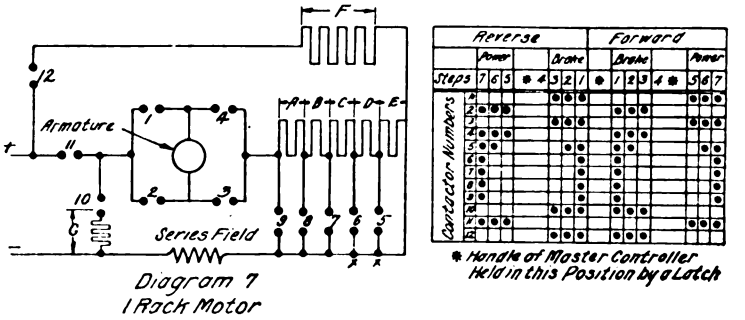


FIG. 6—CONTROLLER CONNECTIONS OF A SERIES-WOUND HOIST MOTOR ON A COAL BRIDGE

that is needed is to determine the torque on the motor shaft by making mechanical calculations. Find the current which flows in the motor, when this torque is exerted, by referring to the motor curve. Provide a rheostat in series with the armature and series field of such value that voltage drop in the rheostat with necessary current flowing will be equal to rated voltage of the motor. Many motors can stand more than rated voltage under this condition, because the current is relatively small. Thus the lowering speed can be much more than the hoisting speed. However, when this resistance is short-circuited to stop the motor, there is a large current peak which causes an increase in the motor voltage before the speed is actually reduced, because the current peak over-excites the field. It is, therefore, necessary to do this short-circuiting in several small steps, else

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the momentarily high voltage, current and speed will cause damage on the commutator. Fig. 6 shows controller connections for such a motor. Resistance blocks *E*, *F* and *G* are proportioned for the uniform acceleration of the motor under load. Blocks *C* and *D* are added to give total resistance sufficient for lowering at high speed. This particular controller is arranged to give a limited amount of power to the motor in a lowering direction for the purpose of accelerating the motor quickly when the bucket is being opened.

Electricity for coal and ore bridge operation is now a necessity. No other form of power is capable of being transmitted so readily to the place where it is needed for use. Electricity has proved to be far cheaper than steam for this purpose. Practically all of the unloading of boats on the Great Lakes is done with electric power.

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# CONCATENATED INDUCTION MOTORS FOR ROLLING MILL DRIVE

BY WILLIAM OSCHMANN

ABSTRACT OF PAPER

The paper describes a six-speed concatenated induction motor set for driving the finishing rolls of a 12-stand continuous mill. Analysis of the conditions in this mill showed that the use of a low-pressure turbine would lead to the waste of a large amount of exhaust steam and that the alternating-current turbine plant which was in operation had ample reserve capacity for driving the mill. The large number of speeds required suggested the use of a direct-current motor, but as this required a motor-generator set it was found to be more expensive than the concatenated motor. An induction motor operating with a speed regulating set was also considered but its disadvantages lay in the fact that a commutating motor or synchronous converter would be required, the performance of which at the frequency employed being questionable. The concatenated set installed consists of a double-wound main motor and single-wound secondary motor, both stators mounted on a common bed-plate and both rotors on a common shaft. The larger motor has both a 14- and 16-pole stator winding and the secondary motor has its winding arranged for four- and eight-pole connections. The control system is described in detail; its operation is very simple, so that no regular attendant is needed. The motor has six definite speeds and two additional resistance speeds, and while the control is somewhat complicated it has been made so nearly foolproof as to make a special attendant unnecessary. As a result of the year's operation there have been but three interruptions, the total loss of time due to which has been 68 minutes.

THE USE of a six-speed concatenated induction motor for rolling mill work is of more than passing significance at this time, and a discussion of the various factors which determined the selection of this type of drive, and the results obtained, will no doubt be of interest. This motor is used to drive the finishing rolls of a twelve-stand continuous mill. The output of the mill consists of round steel rods ranging from 23/64 to 1½ in. (9.1 mm. to 38 mm.) in diameter, also small flats, squares and special sections. The former general arrangement of this mill is shown by Fig. 1.

The two heating furnaces are of the continuous type, the billets being conveyed from the furnaces at *A* to the roughing rolls of the continuous mill at *B*, by a chain-driven roller conveyer.



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The roughing stands are twelve in number, all two-high, and are driven through spur and bevel gears by a 44 by 60 in. (112 by 152 cm.) simple non-condensing Corliss engine, running at about 65 rev. per min. average speed. The number of roughing stands used depends upon the size of the finished bars. In rolling some of the larger sizes, but six or eight of the twelve stands are used.

From the roughing stands, the bars are delivered through pipe conveyers to the finishing rolls. These are four stands of two-high 11-in. (28-cm.) diameter rolls, and were formerly belt-driven by a 28 by 36 in. (71 by 91 cm.) simple non-condensing engine, running at speeds varying from about 85 to 145 rev. per

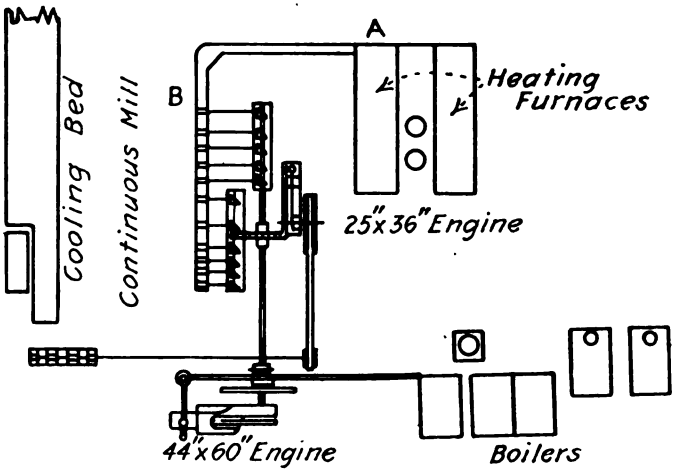


FIG. 1

min., the engine and mill speed being adjusted to suit the size of material rolled. Changes in roll speed were obtained by varying the engine speed, the engine governor being driven through friction disks, thereby allowing the engine speed to be readily changed.

The engine belt wheel was 218 in. (554 cm.) in diameter, the mill pulley 65 in. (165 cm.) in diameter, giving about 3.35 to 1 speed ratio, thus giving a speed range on the rolls from about 285 to 480 rev. per min. The four stands of rolls are used on this mill for practically all sizes; on certain sections, however, but two stands are used.

Steam for operating the engines was obtained from the

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boiler plant shown in Fig. 1, consisting of two boilers equipped with chain grate stokers, and three hand-fired boilers. The balance of the mill equipment consists of a rope-operated cooling bed, shears, scales and rod coiler.

The extreme speed range of 285 to 480 rev. per min. on the finishing stands of this mill is directly due to the inability to roll $1\frac{1}{2}$-in. (38-mm.) rods at a higher speed than 300 rev. per min., or to secure sufficient tonnage of the small sizes without a higher speed, the large number of sizes rolled making impossible the ideal mill arrangement of a single-speed mill, rolling a practically constant-size product.

This mill was built a number of years ago, and has undergone a gradual increase in speed and output, until the capacity was fixed by the inability of the 28 by 36 in. (71 by 91 cm.) engine to stand further increase in speed or output. The maintenance of this engine and the mill belts was high and the overall economy low. For these reasons it was decided to replace this engine by a larger and more powerful engine or some other type of drive. It was readily seen that an engine and belt-driven mill at a higher speed would not be desirable (the belt speed of the 28 by 36 in. engine being about 8000 ft. (2440 m.) per min. when rolling the small sections and it being impracticable to reduce the size of the mill pulley). An engine with a gear or rope driven and a higher first cost, than a motor-driven mill, also a larger figured operating cost, due principally to about 25 per cent higher coal cost at the mill than at the steel company's central power plant.

This mill presented some very interesting features: first, the different speeds required; second, the fact that the steel company had an a-c. turbine power plant with ample reserve capacity for driving the mill; and third, that the exhaust steam from the 44 by 60-in. (112 by 152 cm.) engine seemed to offer an ideal exhaust steam turbine location.

Tests were made on both mill engines in order to determine the power requirements of the finishing rolls and the exhaust steam available from the 44 by 60-in. engine, also the time relation between the power requirements of the finishing rolls compared with the steam supply from the 44 by 60-in. engine.

These tests were made by taking simultaneous continuous indicator cards on both engines, and mill speeds and the work in both mills being observed at the same time. Several tests of different sizes were made. The results of some of these tests are shown on Curves 1 to 19.

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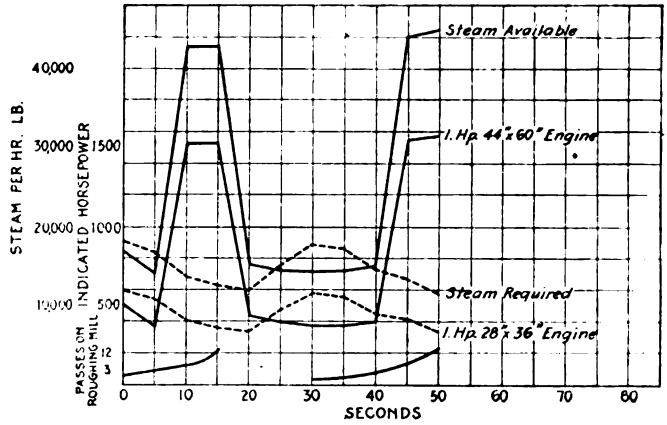
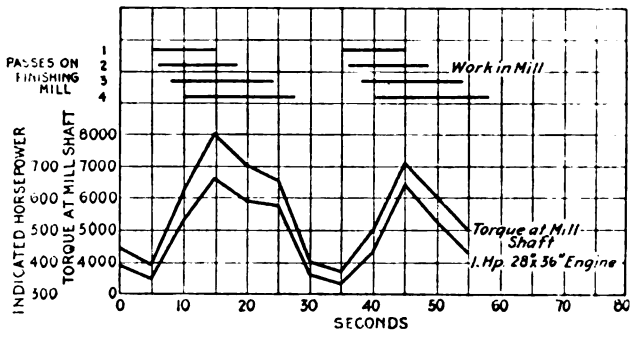
Curve 1 is for $\frac{3}{8}$ in. (9.5 mm.) diameter round rods, and shows the horse power of each mill, also the exhaust steam available from the 44 by 60 in. engine, and the steam required by an exhaust steam turbine to drive the finishing rolls. These tests




CURVE 1—$\frac{3}{8}$-in. Rounds.

showed that sufficient steam was available, but that a small regenerator would probably be required. Tests on this size gave about 500 h.p. as the average power required and also showed a maximum mill speed of 472 rev. per min., and an




CURVE 2—$\frac{3}{8}$-in. Rounds.

average speed of 462 rev. per min. Curve 2 is for a test of the 28 by 36 in. engine on this size. These tests show a peak torque of about 8000 lb. (3630 kg.). The maximum steam demands are greater than the minimum steam available; the periods of insufficient steam supply are extremely short. Curve 3 gives

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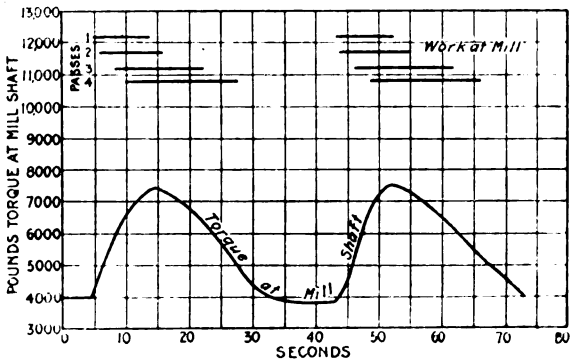
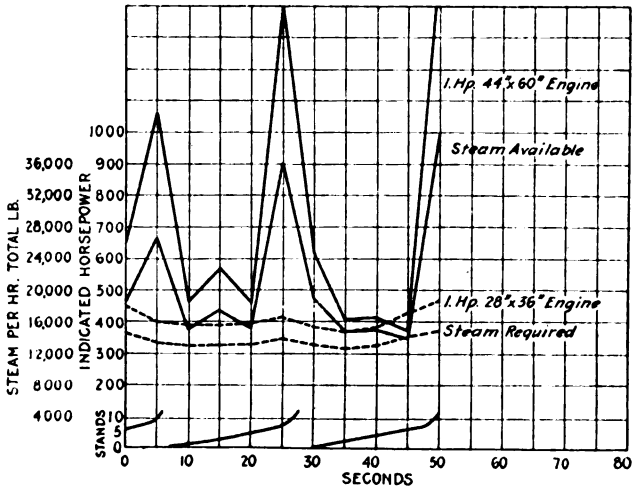
the calculated duty cycle at the maximum mill output, the effective torque being 6000 lb. (2720 kg.), the h.p. 545, and the peak h.p. about 635.




CURVE 3—$\frac{3}{8}$-in. Rounds

Curve 4 is for 29/64-in. (11.5-mm.) round steel rods, and shows an abundance of exhaust steam. The maximum mill speed on this size was 456 rev. per min. and the average about 442 rev.




CURVE 4—29/64-in. Rounds

per min.; the r.m.s. horse power was 425. The peak torque was about 6000 lb. (2720 kg.), and the peak h.p. about 500. Curve 5 is for a test of the 28 by 36 in. engine on this size. Curve 6

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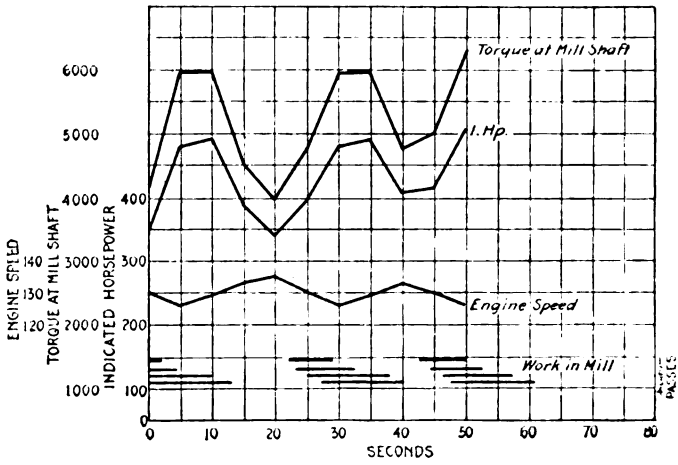
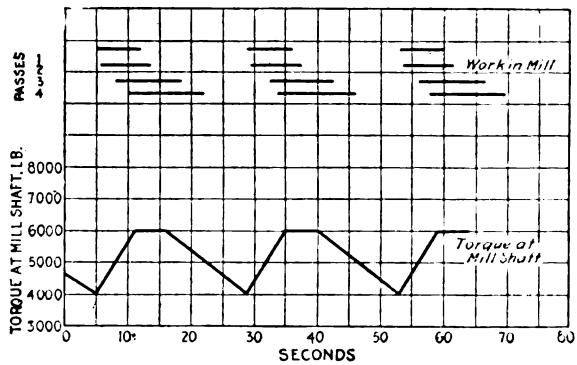
gives the calculated duty cycle at the maximum mill output, the r.m.s. torque being 5400 lb. (2450 kg.), the h.p. 488, and the maximum horse power about 573.




CURVE 5—29/64-in. Rounds

Curve 7 is for 47/64 in. (18.6-mm.) round rods, and shows the steam supply to be less than the steam required; this is due to but eight stands of roughing rolls on the continuous mill being used. This curve shows that in order to secure the best results




CURVE 6—29/64-in. Rounds

a mixed-pressure turbine and a small regenerator would no doubt be necessary. On this test the maximum mill speed was 448 rev. per min., the average 432 rev. per min., and the r.m.s. horse power 639. Curve 8 is for a test of the 28 by 36 in.

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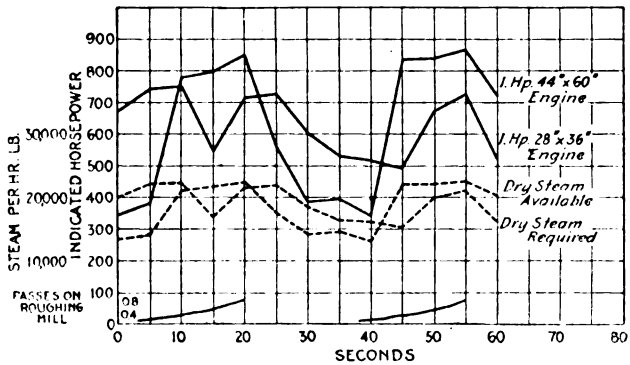
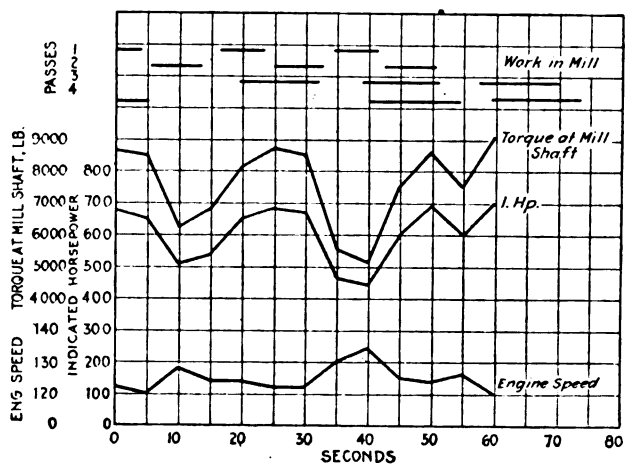
engine on this size. This test shows a maximum torque of 9300 lb. (4220 kg.), and a maximum h.p. of 740. Curve 9 gives the calculated duty cycle at the maximum mill output, the r.m.s.




CURVE 7—47/64-in. Rounds

torque being 8300 lb. 3760 kg., the horse power 662, and the maximum horse power 780.

Curve 10 is for $\frac{7}{8}$-in. (22.2-mm.) round rods and shows that




CURVE 8—47/64-in. Rounds

the steam available is about equal to that required, but that a regenerator should be used. The maximum observed mill speed on this size was 382 rev. per min., and the average about 360 rev. per min., with a horse power of 510. Curve 11 is for

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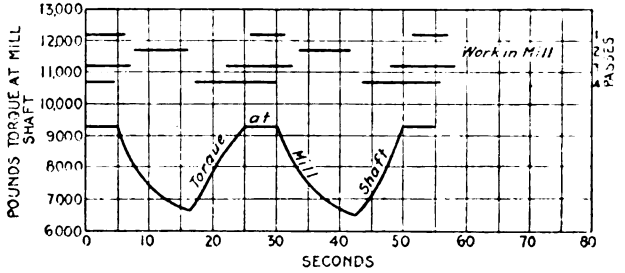
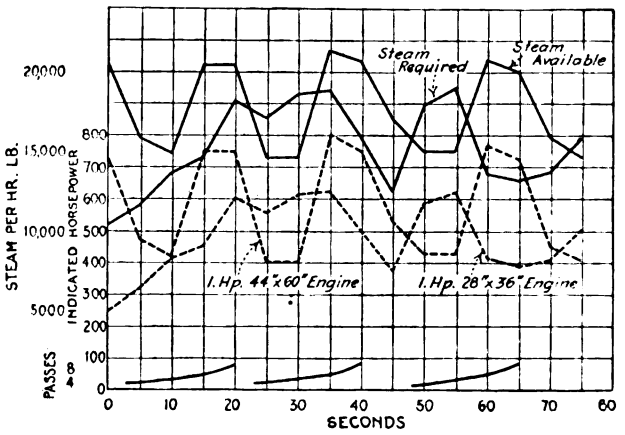
a test of the 28 by 36 in. engine on this size. The tests of this size show a maximum torque of nearly 10,000 lb. (4536 kg.) with about 650 horse power demand. Curve 12 gives the calculated duty cycle at the maximum mill output, the r.m.s.




CURVE 9—47/64-in. Rounds

torque being 8400 lb. (3810 kg.), the horse power 575, and the maximum horse power 650.

Curve 13 is for 63/64-in. (25-mm.) round rods and shows that the steam available exceeds the steam required. This is




CURVE 10—$\frac{7}{8}$-in. Rounds

due to but two stands of finishing rolls being used. The maximum observed mill speed was 312 rev. per min., the average about 300 rev. per min., and the r.m.s. horse power 340. Curve 14 is for test No. 2, and Curve 15 for test No. 4 on this size. In test No. 2 both passes were in the mill at the same time,

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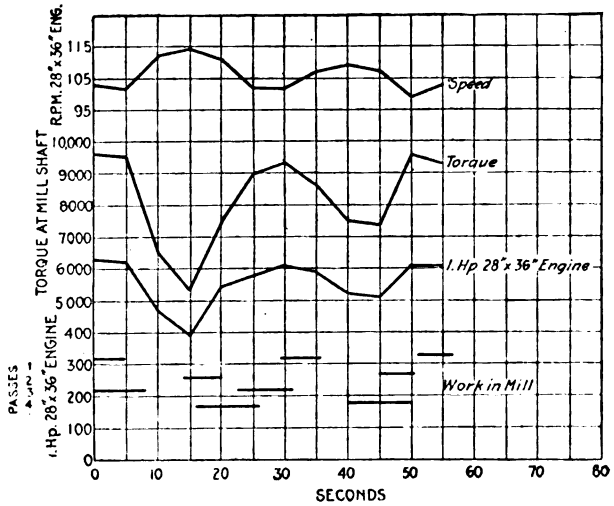
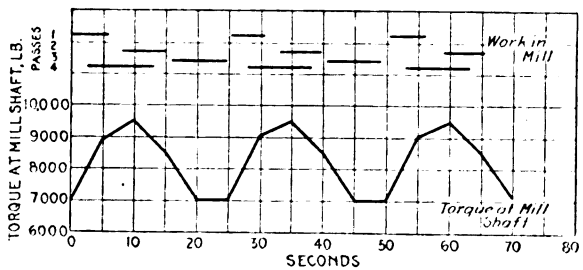
resulting in very high peaks with long rest periods between, while in test No. 4 the two passes did not coincide. The total amount of work done, whether rolling is done with high peaks and long rest intervals, or low peaks and shorter rest periods,




CURVE 11—$\frac{7}{8}$-in. Rounds

is practically the same. In the calculated duty cycle for the maximum mill output (Curve 16), the peaks are taken on the basis of the two passes not occurring at the same time; this gives a cycle similar to test No. 4, the r.m.s. torque being 6800 lb.




CURVE 12—$\frac{7}{8}$-in. Rounds

(3080 kg.), the horse power 414, the maximum torque 9800 lb. (4445 kg.), and the horse power 545.

Curve 17 is for $1\frac{1}{4}$-in. (31.7 mm.) round rods and shows the steam required to be in excess of the steam available. The

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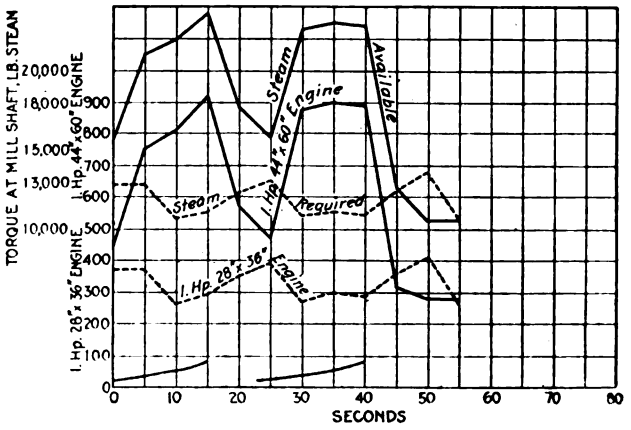
maximum observed mill speed was 314 rev. per min., the average being 285 rev. per min., and the horse power about 400. Curve 18 is for a test of the 28 by 36-in. engine on this size, and shows high peaks when passes one and three coincide. Curve




CURVE 13—63/64-in. Rounds

19 is the calculated torque to give maximum mill output and gives an effective torque of 7500 lb. (3400 kg.), with a horse power of 604, and a maximum horse power of 640.

A summary of the foregoing tests gives:

| Diameter of Rod | | Mill speed | | Effective h.p. | Peaks h.p. | Lb. steam available | Lb. steam demanded | Mill speed desired |
|---|---|---|---|---|---|---|---|---|
| in. | mm. | max. | Average | | | | | |
| 3/8 | 9.5 | 472 | 462 | 500 | 669 | 25,300 | 14,900 | 475 - 480 |
| 29/64 | 11.5 | 456 | 442 | 425 | 509 | 21,200 | 13,500 | 475 - 480 |
| 47/64 | 18.6 | 448 | 432 | 639 | 738 | 18,250 | 19,100 | 420 - 435 |
| 7/8 | 22.2 | 382 | 360 | 510 | 635 | 17,600 | 15,300 | 360 - 375 |
| 63/64 | 25.0 | 312 | 300 | 340 | 506 | 18,400 | 10,250 | 305 - 310 |
| 1 1/4 | 31.7 | 314 | 285 | 400 | 600 | 10,500 | 13,000 | 285 - 300 |

The test results show that a large amount of exhaust steam would be lost in case the low-pressure turbine were used for driving the finishing rolls directly. Also it was found that the low-pressure turbine would be wasteful of steam if the turbine speed varied with the mill speed. Gearing the turbine to the

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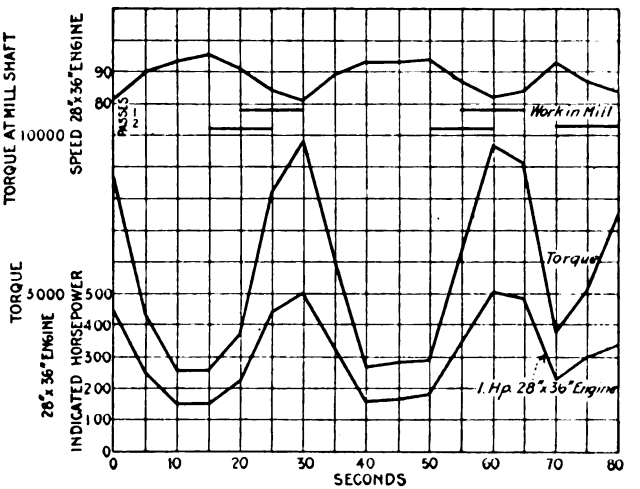
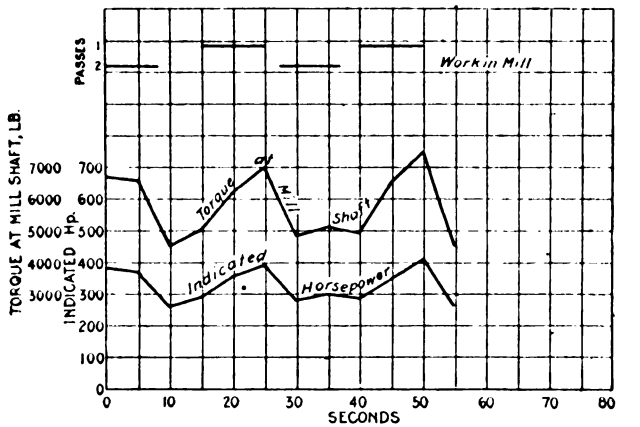
mill was not looked upon favorably, as the experience with several turbine gears on pump work had not been entirely satisfactory. A further objection to the turbine was the cost




CURVE 14—63/64-in. Rounds

of condensing water and the investment necessary for pumping equipment and pipe lines.

A careful consideration of the various drives resulted in the




CURVE 15—63/64-in. Rounds

decision to install a motor drive, either a-c. or d-c., and obtain power from the steel company's central power plant. It was found that this would give an economical drive and be lower

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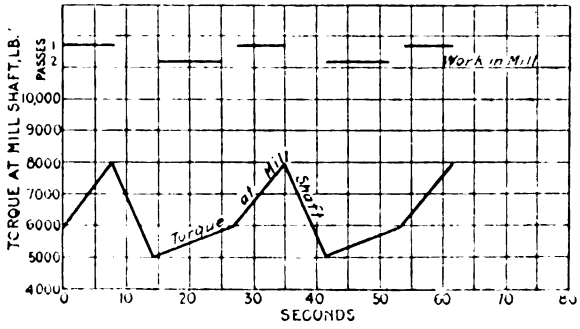
in first cost than either a rope or geared engine. Also, the use of a motor would not interfere with the future installing of the exhaust steam turbine, which could operate in parallel with the company's power plant.

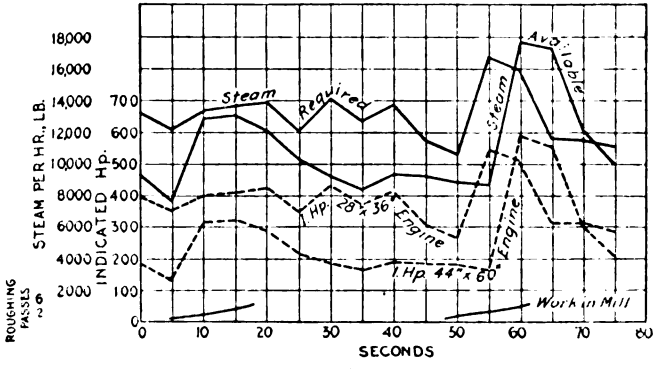
At this time, it may be of interest to state the reasons which




CURVE 16—63/64-in. Rounds

influenced the purchase of a concatenated motor instead of, first, a direct-current motor, or second, an induction motor operating with a speed-regulating set.

(1) The direct-current motor was entirely practical, but presented no advantages over the concatenated motor, except




CURVE 17—1¼-in. Rounds

that smaller speed steps were possible. This was negligible because the concatenated set gave as many speeds as were necessary. The disadvantages of the direct-current motor were, that it was more expensive and, as it required a motor-generator set, less efficient.

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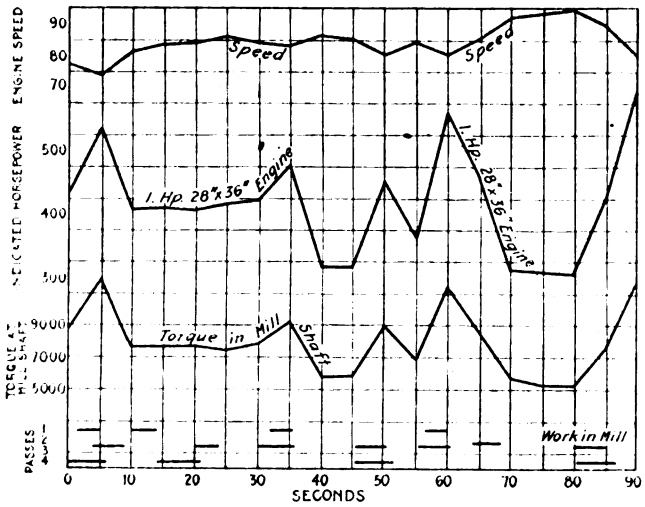
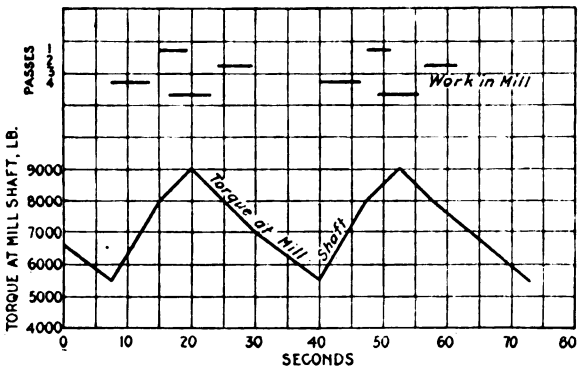
(2) The speed-regulating set would have about the same or slightly better efficiency than the concatenated motor, would be about the same in first cost and would have a higher power




CURVE 18—1¼-in. Rounds

factor at low speeds. Its disadvantage lay in the fact that a commutator motor or synchronous converter would be required. Little was known about the performance of a commutator motor




CURVE 19—1¼-in. Rounds

operating on the high frequency which would be obtained at this mill, commutator motors on mill work operating at frequencies around 20 cycles per second not being in satisfactory

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service either here or abroad, and it is questionable if at the present time a guarantee for a satisfactory commutator motor could be obtained for the work of this mill.

Using a synchronous converter and a motor, or a motor-generator set, would not give as high efficiency as a concatenated set.

Both of these systems involved the use of commutators and would require more attention than the concatenated set. They also had the disadvantage of requiring a high mill speed before the reduced speeds could be obtained, whereas the motor installed has no regular attendant, and with the control properly adjusted, the motor starts accelerates and drops into concatenation without exceeding the synchronous speed of the combined motors.

An attempt was made to limit the mill to two or three speeds. A 16-pole main and a 4- and 8-pole secondary motor, would give poles and speeds as follows:

| Main motor | Secondary motor | Both motors | Synchronous speed |
|---|---|---|---|
| 16 poles | none | 16 poles | 450 rev. per min. |
| 16 " | 4 poles | 20 " | 360 " |
| 16 " | 3 " | 24 " | 300 " |

This eliminated the 400-rev. per min. speed, which is one of the most important on the mill, about 40 per cent of the mill output being on this speed.

Changing to a 14-pole main motor would give 514, 400 and 327 rev. per min. This would give a dangerously high speed for the $1\frac{1}{4}$ and $1\frac{1}{2}$-in. (31.7-and 38-mm.) rods, and would also eliminate the 450-rev. per min. speed, which is important on some sizes.

Leaving the secondary motor unchanged, and placing a double winding on the main motor, gave all the speeds required. This resulted in a 4- and 8-pole secondary motor and a 14- and 16-pole primary motor, which combination gives the following speeds:

| Main motor, | Secondary motor | Both motors | Synchronous speed |
|---|---|---|---|
| 14 poles | none | 14 " | 514 rev. per min. |
| 16 " | " | 16 " | 450 " |
| 14 " | 4 poles | 18 " | 400 " |
| 16 " | 4 " | 20 " | 360 " |
| 14 " | 8 " | 22 " | 327 " |
| 16 " | 8 " | 24 " | 300 " |

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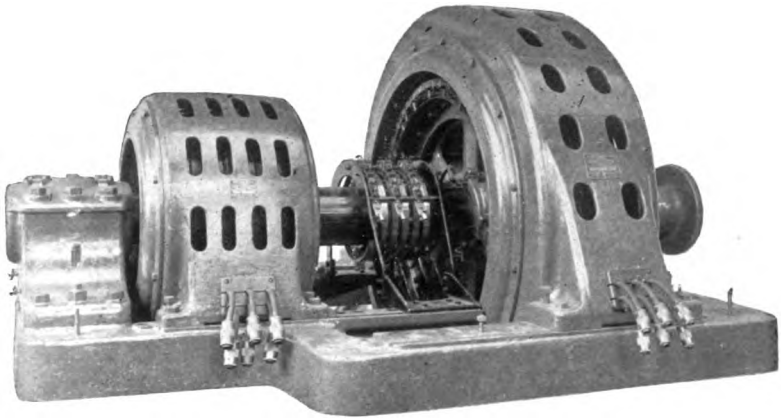
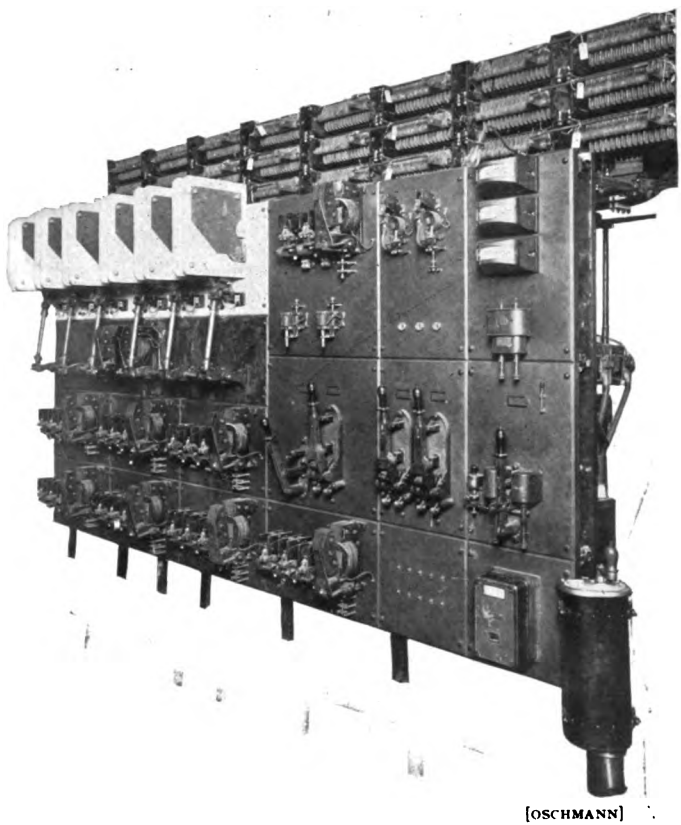


[OSCHMANN]

FIG. 2—2200-VOLT 600-H.P. CONCATENATED INDUCTION MOTOR SET ARRANGED TO OPERATE AT SIX SYNCHRONOUS SPEEDS, BUILT FOR OLIVER IRON AND STEEL COMPANY.



[OSCHMANN]

FIG. 4—SWITCHBOARD FOR PRIMARY AND SECONDARY CONTROL CIRCUITS OF SIX-SPEED CONCATENATED INDUCTION MOTOR.

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All these speeds are obtained by direct concatenation; theoretically, speeds corresponding to 6, 8, 10 and 12 poles can also be obtained by differential concatenation.

It was decided to install this motor, the motor to consist of a double-wound main motor and single-wound secondary motor, the first or primary motor to be 14 and 16 poles and have a wound rotor, the second or secondary motor to have its winding arranged for 4 and 8 pole connection, its rotor to be of the squirrel cage type. Both stators were mounted on a common bed-plate and the rotors on a common shaft, resulting in the motor shown in Fig. 2.

The larger motor receives three-phase energy at 2200 volts, 60 cycles, on either a 14- or 16-pole stator winding. Both 14- and 16-pole windings lie in the same stator slots and have the same coil pitch and coil size. The coil connections of the 14-pole windings are brought out on one side of the frame, the coil connections for the 16-pole winding being on the opposite side. This makes the connections of either winding readily accessible. The windings on the rotor of this motor are similarly arranged. The six leads from the rotor windings are connected to six split bronze collector rings mounted on the shaft between the two motors. These rings can be easily renewed.

The small motor has a single stator winding which can be connected in either four- or eight-pole combination; the pole changing is accomplished by means of oil switches located on the motor control board. The rotor of this motor is of the squirrel-cage type and has electrically welded bars and end rings. The rotor bars are of sufficient cross-section to resist the action of centrifugal force and will not bend out and damage the stator winding, should they become detached from the end rings.

The floor space taken by the complete unit is 14 ft. 8 in. by 10 ft. 7 in. (4.47 by 3.22 mm.), and the greatest height above the floor is 6 ft. 10 in. (2.08 mm.). The rotors are 5 ft. 9 in. (175 cm.) and 2 ft. 10 in. (86 cm.) in diameter, respectively, mounted on a shaft 14 in. (356 mm.) in diameter. The general construction of the motor is heavy. The rotor spiders are of cast steel and the motor is built to stand reversing at full speed. The two bearings each 8 by 20 in. (203 by 508 mm.), are self-aligning and of the ring-oiled type. The motor and mill are connected by a flexible coupling, the bearing next the mill and the coupling hub forming a thrust bearing. The brush holders for the col-

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lector ring brushes can be removed and either stator can be slipped aside to give access to any part of the stator or rotor windings.

The motor was installed about where the mill pulley formerly was, the present mill plan being shown in Fig. 3.

For the operation of the motor no regular attendant is needed, as the changing of speeds is simple and requires no electrical knowledge or experience. The engineer on the 44 by 60 in. (112 by 152 cm.) engine attends to all speed changes and also

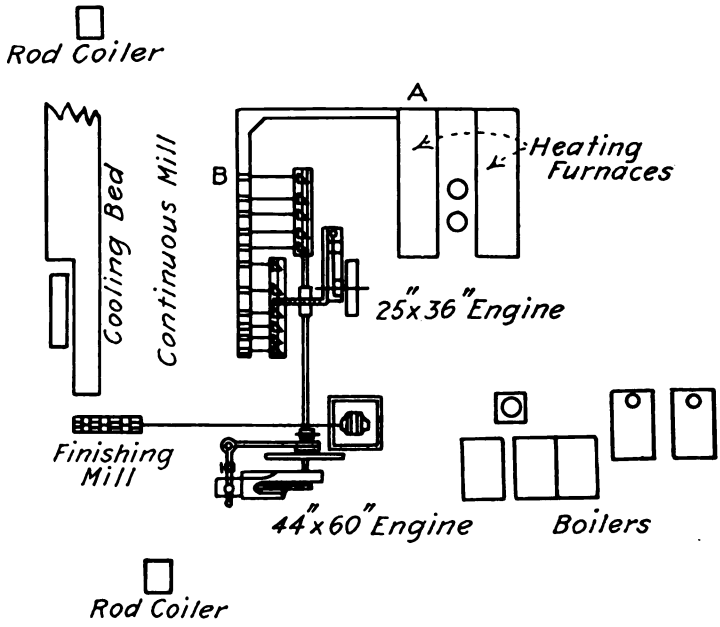


FIG. 3

starts and stops the motor. The controller for the motor is mounted adjacent to the throttle of the engine. In practise it has been found that, having the motor controller near the engine throttle, the engineer can handle both mills easily, the extra work and attention required being almost negligible.

The ease and simplicity in handling the mill is one of the best points in favor of the concatenated motor, as has been shown repeatedly in stopping the mill and backing out "stickers", or pieces caught in guides and refusing to go through rolls. The motor can be stopped, reversed and the sticking rod backed

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out, the motor again stopped, restarted and immediately accelerated to full operating speed. This is generally done in time to roll the billets coming through continuous mill and prevent their being scrapped. On several occasions this has taken place, the quick stop and start saving about a third of a ton of steel from becoming scrap. The total time of stopping, backing out, stopping and accelerating to operating speed, was less than a minute. The stopping and reversing was easily done, and no apparent strain or distress on motor or control was noticeable.

The control board for this motor is shown in Fig. 4. The wiring diagram is shown in Fig. 5. The choke coils, lightning arresters and disconnecting switches are mounted on the wall of the motor house and are connected to the control board through series transformers for wattmeter and overload relays to switch *A*. These transformers are connected in Z and give overload protection on all three phases.

Oil switch *A* is a triple-pole circuit breaker, having inverse-time-limit overload trip and low-voltage release, and is also provided with a magnetically operated lockout which prevents switch *A* from being closed unless both main line contactors *F* and *R* are open. This is provided to prevent the mill from starting should the engineer attempt to close switch *A* and not notice that the main line contactors had remained closed.

From switch *A*, current passes to the forward and reverse main line contactors *F* and *R*, one phase passing through a series transformer which operates the current-limit relays *CR* which control the resistance contactors.

*F* and *R* are three-pole, 2200-volt, magnetically operated air-break contactors. A mechanical and electrical interlock is provided between these contactors. The electrical interlock is not the conventional interlock disks working on the connections of the magnet coils, but consists of a small shunt transformer *TL* with its primary connected across one phase of the contactors are shown (Fig. 5). The secondary of the transformer operates the small contactor *L*. Contactors *F* and *R* have their operating circuit closed through contactor *L* or the interlock on *L*. As long as there is potential on the motor, contactor *L* will remain closed and thereby prevent either *F* or *R* from closing. As soon as *L* opens, either *F* or *R* can close, depending on the position of the master controller. This method of interlocking was deemed necessary, as the operation of the contactors is so

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rapid that in reversing the motor, one contactor might close before the arc on the other was ruptured, and thereby produce a short circuit through the arc on the open contactor. The present arrangement has proved entirely satisfactory.

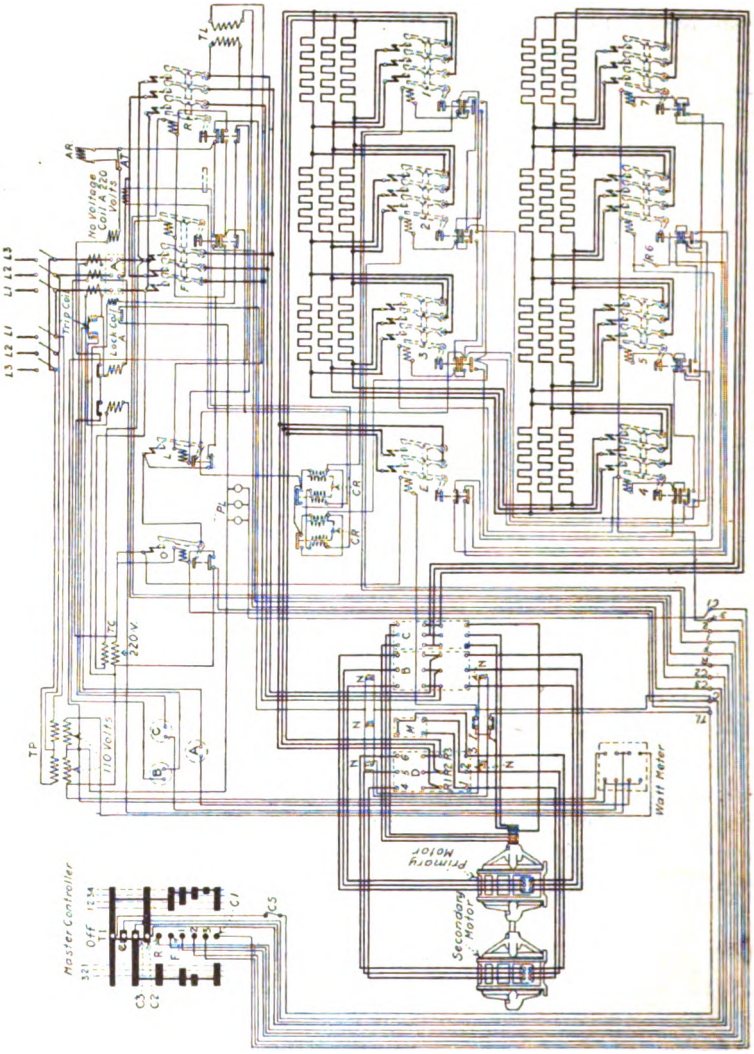


FIG. 5

The operation of the main line contactors shows that double-pole contactors would be as satisfactory as the triple-pole contactors installed. As the arcs, particularly the heavy arcs,

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are always single-phase, switch *B* might also be double-pole instead of triple-pole.

From contactor *F* and *R* current passes to oil switch *B*, where connection is made to either the 14- or 16-pole stator winding of the primary motor. Oil switch *B* is mechanically connected to oil switch *C*, so that *B* and *C* are operated by one handle. Switch *C* controls the rotor winding of the primary motor. Closing switch *B* on the 14-pole side will also close switch *C* on its 14-pole side. From switch *C* the current passes to a grid resistance mounted above the control board. This resistance is ample to reduce the mill speed to about 50 rev. per min. and hold it at this point for 15 to 20 minutes, the friction of the mill being the only load. This low speed is used to adjust the rolls and roll trial bars. The end of the resistance is either short-circuited by contactor *E* or the current passes into switch *D*, where it is directed into the stator of the secondary motor. Switch *D* is mechanically connected to switch *M*. These switches give either the 4- or 8-pole connection on the stator of the second motor. Closing switch *D* on the 1, 2 and 3 side gives a single-circuit eight-pole delta connection to the stator of the secondary motor; closing *D* on the 4, 5 and 6 side also closes switch *M* and gives a double-circuit four-pole star connection to the stator of the secondary motor. Switch *D* is provided with interlock switches *I* and connected to contactor *E* and arranged to close contactor *E* when switch *D* is open. To avoid having the mill try to accelerate from a concatenated to a direct speed should switch *D* open and thereby close contactor *E*, switch *D* is provided with a lock *N*, so that it cannot be opened or closed unless the master controller is placed on the off point and switch *A* is open. Switches *V* and *C* are provided with similar locks. The pilot lights *PL* indicate the position of the master controller; their circuit is closed when the controller is on the starting or running points. Current for the pilot lamps and small solenoids *N* which operate the locks on switches *A*, *B*, *C* and *D* is obtained from the potential transformers *TP*, and is independent of the position of switch *A*.

Contactors 1 to 7 are triple-pole low-voltage contactors and are arranged to short-circuit portions of the resistance; they are connected so that a contactor sticking or remaining closed will not produce dangerous currents in starting or reversing. These contactors are controlled by current from transformer *TC*, which is connected to the control side of switch *A*; current from the transformer passes through contactor *O* to current limit relays,

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*CR*, which are set to close the contactors in regular sequence when the starting current drops to about full-load value. When operating on the 14- or 16-pole speeds contactors 6 and 7 will remain open and give a 10 per cent slip at full load; by closing switch *R*6 contactor 6 will close and give a 5 per cent slip at full speed. Contactor 7 is always open on the 14- or 16-pole speed.

When operating on the concatenated speeds contactor *E* is open and interlocks on *E* are closed, which allows contactors 6 and 7 to close, current limit the same as the remaining contactors, thereby leaving the motor without external resistance in the rotor circuit other than the resistance of the wires. Contactor *O* controls the current for all contactors except itself and contactor *L*. Contactor *O* is used to prevent the motor from starting upon the resumption of power in case of the failure of switch *A* to open should the power supply be interrupted. Contactor *O* opens on failure of power and can only be closed by placing the master controller in the off position.

The master controller is located about 80 ft. (24 m.) distant from the control board, and to guard against the master controller becoming inoperative, switch *CS*, located near the master controller, is provided. The action of switch *CS* is to open all the contactors and oil switch *A* and stop the motor should the master controller be out of order.

A test switch *AT* is provided on the control board which opens oil switch *A*. Resistance *AR* is connected across switch *AT* so that when switch *AT* is open a slight current passes through the low-voltage release coil of switch *A*. This current is just sufficient to neutralize whatever residual magnetism may remain in the armature of the low-voltage release, and causes it to drop at once and open switch *A*.

It will be noted that the starting resistance is connected between the rotor of the main and the stator of the secondary motor. The circuit between the motors is established before the motors are started and the entire starting current passes through the secondary motor. This simplified the control of the mill and makes the starting simple, as this method allows the mill to come directly to whatever speed the control is set for.

In stopping the mill, the master controller is usually placed in the off position, and the motor allowed to stop gradually. In emergency the motor can be reversed at full speed; in reversing on the concatenated speeds the secondary motor acts as a part of the circuit. The simplicity of this method is obvious.

The operation of this control is as follows;

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Disconnecting switches are closed and power is on the lines. Master controller is on off point and oil switch *A* is open.

### For Direct Speeds

Close switch *B* for either 14 or 16 poles. Close switch *A*. Closing switch *A* closes contactor *E* through interlock *L* on switch *D*. Contactor *O* also closes, its circuit being closed through segment *C* on master controller. After closing, *O* will remain closed regardless of position of the master controller, its holding circuit being established by the interlocks on *O*.

*Starting.* Placing the master controller on the first point closes either *F* or *R*; this puts potential on the main motor and closes contactors Placing the controller on the second point, contactor No. 1 can close. Placing the controller on the third point, contactor No. 2 can close. Placing the controller on the fourth point, contactor Nos. 3, 4, 5 can close. Contactor 6 can close if switch *R*6 is closed; contactor 7 cannot close as its closing circuit is open at contactor *E*. Under operating conditions the master controller is placed directly on the fourth or running point, and the contactors close in regular sequence at about full load value, then control being the usual current limit type for a-c. contactors.

*Reversing.* When master controller is thrown from ahead to reverse, contactor *R* will close as soon as arc on *F* is interrupted, and thereby open contactor *L*.

### Concatenated Speeds

Oil switch *B* is placed on either the 14- or 16-pole connection. Switch *D* is closed for 4- or 8-pole connection. Oil switch *A* is closed, when contactor *O* closes as before. Contactor *E* does not close, however, as its closing circuit is open at intervals *I* on switch *D*.

*Starting, Running and Reversing.* Exactly the same as for direct speeds, except that contactors 6 and 7 will close current limit the same as the rest of resistance contactors.

### Summary

The control as used on this motor is more simple than a speed-regulating control in its operation; it is comparable with the magnetic control of a single-speed motor. The starting, stopping and reversing are as easily accomplished as if the motor were a single speed motor. The only difference in handling as to operate switches *B* and *D* to secure the proper pole connection, and as this is generally done while changing rolls, it causes no delay or inconvenience. The only serious objection to the con-

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catenated set is the low power factor on the concatenated speeds. The low power factor in this particular case has been found to be serious. The power plan has a larger day than night load, so the concatenated set working on the day shift reduces the power factor at the power plant but slightly. The lowest speeds, and therefore the lowest power factor, are generally obtained on the night shift. However, several synchronous motors (installed about five years ago), operate at reduced loads on the night shifts and it has been found that about 100 per cent power factor can be readily obtained at the power plant during the night, and 87 to 90 per cent during the day.

The criticism has been made that the control of concatenated motors is complicated: in reply to this, I would state that this motor has six definite speeds and two additional resistance speeds. Switches and contactors are provided to take care of these speeds and in addition the control has been further complicated in order to make the operation of the motor and control as fool-proof as possible, and thereby make unnecessary a special attendant at the mill.

The motor was installed in June, 1913, up to this time (April 1914) there have been only three mill interruptions, all of which were due to the control apparatus, as follows:

(1) An open circuit at interlock on contactor *F* which allowed low-voltage release to drop and open switch *A*. This interlock consists of a $\frac{1}{2}$-in. (12.7-mm.) copper rod pressing against copper block contactor; the copper rod is insulated and clamped to the contactor. The clamp became loose and allowed the rod to slip out and open the circuit.

(2) Defective low-voltage release coil on switch *A*.

(3) Burnt-out potential coil on one of the current-limit relays *CR*.

The total time lost due to these three interruptions was 68 minutes, and it will be noted that, excepting the first, not one of these interruptions was due to the design or type of the control, but rather to minor defects in manufacture. The motor has easily performed the work demanded of it, and the results obtained have justified the choice of this type of motor drive.

Should the same problem be presented for solution at this time, it would probably be solved in the same manner, notwithstanding the recent advances made in speed-regulating systems. It should also be noted that the ease of handling this motor and the ability to do without a trained operator make this type of motor extremely desirable.

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*To be presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 26, 1914, under the auspices of the Electrochemical Committee.*

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(*Subject to final revision for the Transactions.*)

# STERILIZATION OF WATER BY ULTRA-VIOLET RAYS OF THE MERCURY-VAPOR QUARTZ LAMP

BY M. von RECKLINGHAUSEN

ABSTRACT OF PAPER

Mercury-vapor quartz lamps are applied industrially for the production of ultra-violet rays for the sterilization of water.

To obtain ultra-violet rays economically it is important to study the temperature of the luminous part of the lamp.

There are different ways for measuring the ultra-violet power, based on physical, chemical or bacteriological reactions. Such reactions are compared between them.

The paper refers to the historical development of mercury lamp water sterilizers and the development of pistol lamps for large sterilizing units.

Different germs are of different sensitivity to ultra-violet light.

It is important that the water should be clear when entering the sterilizer.

Description is given of two typical installations, one in Europe, one in America.

Data are given on the power consumption for the sterilization of water by ultra-violet rays.

WITHIN the last five years a new field for the application of electricity has been created in Europe based upon the electrical production of ultra-violet light for the sterilization of water and for other purposes. As this new industry is now being introduced into this country, it is of interest at this time to analyze its basis and principles.

The experimental and development work in this field has been done mainly in France, and prominently identified with it are the names of Courmont, Nogier Henri, Helbronner, von Recklinghausen, Vallet and others. This paper deals particularly with the work done by the writer in collaboration with Messrs. Henri and Helbronner at the Physiological Laboratory of the Sorbonne University.

## THE SOURCE OF ULTRA-VIOLET LIGHT

The only industrially-applied source of ultra-violet light is the mercury-vapor quartz lamp. The spectrum is known by its bright lines in the visible part and by a large number of typical



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lines in the ultra-violet part, as shown in Fig. 1, which is drawn to proportional scale.

When starting this work we soon found that we had to go pretty fully into the question of the measure of the ultra-violet power of the different light sources at our disposal, so as to give the mercury quartz lamps the electrical characteristics which made them most useful for the creation of ultra-violet light. It is a well-known fact that the skin takes a less ghastly hue under the quartz mercury lamp than under the ordinary mercury-vapor lamp. Spectroscopic examination shows that this is due to a considerable increase of the intensity of the red lines in the spectrum of the quartz lamp. This phenomenon was examined somewhat more closely, with the following results:

An ordinary 110-volt lamp was taken, which normally operates at 3.5 amperes and 80 volts; it was operated at different wattages, obtaining thereby, naturally, different temperatures of the mercury arc. A spectro-photometric analysis was made of the five principal colors, composing the visible light of these lamps.

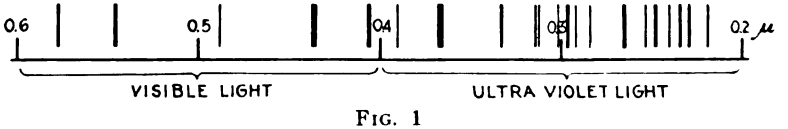


FIG. 1

Assuming the intensity of each color at the lowest wattage as unity, we note that increasing the wattage of the lamp tends to increase the red more than the other colors, as is shown in the curve, Fig. 2. It might therefore be expected that the increase of the ultra-violet rays with increasing temperature of the lamp, would be somewhat like the increase at the violet end of the spectrum, that is to say, proportionately less than at the red end. As will be seen from what follows, this is not the case. There is obtained, on the contrary, a considerably greater increase in ultra-violet than in violet rays with increasing temperature of the lamp.

### QUANTITATIVE MEASUREMENT OF ULTRA-VIOLET LIGHT

The candle power standard for ordinary light is not a physical standard but a physiological one, being the effect on the eye of the sum of the visible wave lengths emitted by a defined source of light, produced by a defined fuel, burning in a defined way.

The eye not being sensible to ultra-violet, we only consider

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the total *visible* energy sent out by this standard lamp. From the start it is therefore clear that if we want to define a standard of ultra-violet light we must do one of two things, namely: either define the standard in energy units (and wave lengths) or imitate our method of defining that standard of ordinary light and define our standard ultra-violet as the unit of effect produced by the ultra-violet rays. However, it is likely that the sums of such effects may be identical if *one kind of an effect is chosen* and may not be identical if another type of an effect is chosen.

The only true way of defining the power of the rays is by the analysis of the spectrum, and the determination of the energy

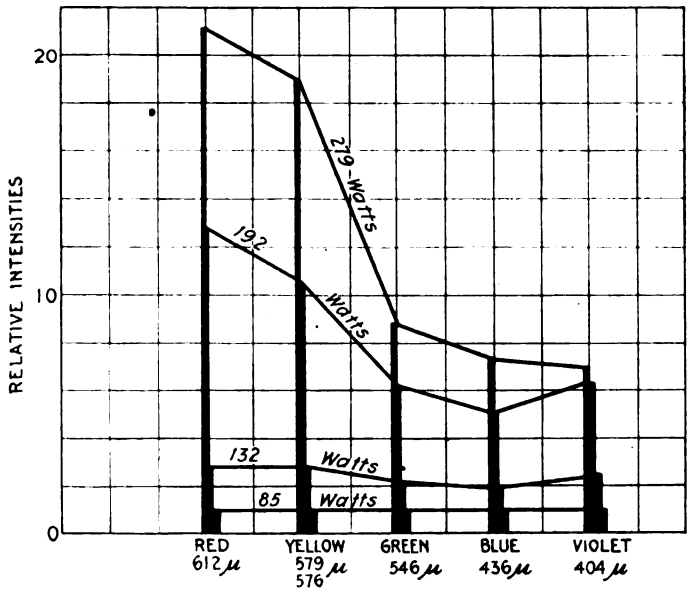


FIG. 2

sent out by each wave length. This method, however, is extremely inconvenient and, after all, does not give us what we want in practise.

It is therefore better to choose as a unit, some value of the particular effect which concerns the work in hand. If we want to follow chemical reaction under the ultra-violet light we choose arbitrarily as a unit one in which the desired reaction takes place in a defined way after a unit period of exposure to all the rays of the lamp. We may therefore say that for every type of reaction under the ultra-violet light we have to define a new unit of actinic power.

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The different ways of examining the power of the ultra-violet spectrum are the following:

(1) Analysis of the distribution of energy in the spectrum. The way to measure this is to measure the amount of heat developed by a certain wave length, the measurements being made by means of a bolometer or thermoelectric couple.

Fig. 3 shows the distribution of energy in the spectrum of the mercury lamp as worked out by Ladenburg. Fabry has used different filters or screens to separate out different wave lengths. He finds that a 110-volt lamp burning at 27 volts, 3.5 amperes, sends out energy of which the distribution is as

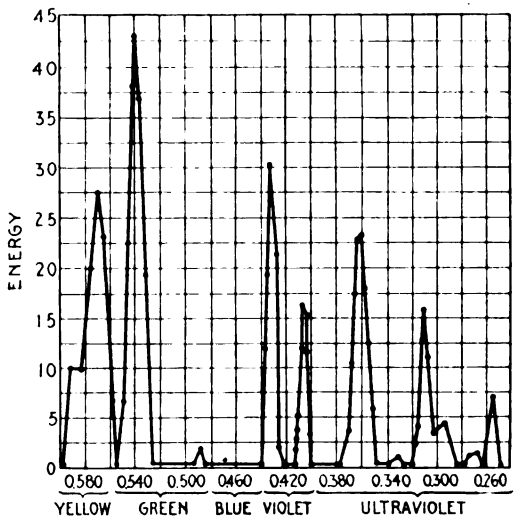


FIG. 3

follows: 93.7 per cent in the infra-red; 3.6 per cent in the visible spectrum; 2.2 per cent in the ultra-violet spectrum from $0.366\mu$ to $0.313\mu$; 0.5 per cent in the ultra-violet from $0.313\mu$ down to $0.253\mu$. As to absolute values, Fabry found that at one meter distance from the lamp, one square centimeter received 125 ergs per second of visible light and 76 ergs per second of ultra-violet light down to $0.253\mu$.

(2) Ultra-violet light falling on a condenser will ionize the air and this will be followed by a discharge of the condenser. This method could probably be used for analyzing the power of different wave lengths or for establishing an arbitrary standard of ionization by ultra-violet light.

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(3) Many chemical reactions are produced to a greater extent by ultra-violet light than by visible light. The so-called Eder reaction of precipitation of calomel, which goes on very much faster under ultra-violet light than under visible light, is an example. The dissociation of gaseous hydrochloric acid and particularly the dissociation of silver salts may also be mentioned. The typical reaction of this latter kind is the blackening of photographic paper; this, for certain types of paper, occurs four times as quickly under a naked quartz lamp as it does under the same lamp with glass interposed, showing thereby that the ultra-violet part of the spectrum has a very much stronger effect than the visible part. The photographic plate allows us to compare the strength of individual lines of equal wave lengths but coming from different sources, by comparing the times of exposure necessary to obtain equally strong pictures of such lines.

(4) Bactericidal or abiotic action. The first real spectrum analysis of this kind we owe to Ward, who threw the spectrum of a quartz lamp on an infected agar plate. The parts of the plate which were exposed to the violet end of the spectrum would not show any growth of colonies, while the parts which were exposed to the red end of the spectrum would develop growth.

With the above-cited chemical reactions it is fairly easy to create a unit; for instance, precipitation of a unit quantity of calomel at the unit distance in the unit time. If, however, we choose a unit of bactericidal reaction, we find that cultures of microbes vary so much with age and other conditions that it is impossible to get sufficiently constant results upon which to base a unit reaction. If we wish, therefore, to use abiotic reaction as a unit we must first determine the sensibility of our reactive material, that is, the germ culture on hand, by exposing samples of it to the light of a lamp which is otherwise standardized. This means creating a laboratory-standard lamp which is so operated that it will always produce the same amount of ultra-violet rays.

The abiotic reaction which we chose as most convenient to handle was the measure of the exposure necessary to kill paramecias, these being similar to water bacteria and fairly easy to cultivate and to observe directly under the microscope, as they have a very violent motion when living and, naturally, no motion when dead. The method of procedure is to take a drop of such culture, expose it at a definite distance under the lamp, count

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the seconds necessary to make them motionless, and compare the figures thus obtained with figures obtained under the standard lamp.

As the photographic paper method is infinitely more simple to handle, it was considered advisable to see whether it would not

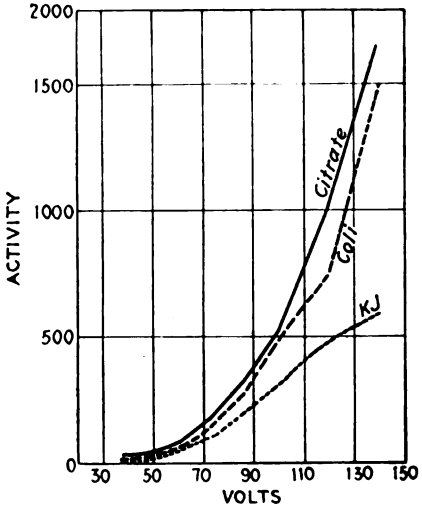


FIG. 4

correspond closely enough with the abiotic reaction to be a useful check upon the abiotic power of the quartz lamp. Fig. 4 shows the observations made simultaneously by the two methods, using a lamp operating at various voltages. Analyzing the results obtained by methods 1, 3, and 4 with lamps operating

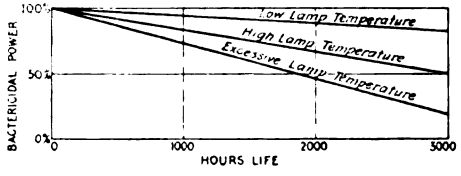


FIG. 5

at different temperatures (see Fig. 4), we may conclude that the relative increase in ultra-violet rays with increase in lamp voltage is considerably stronger than the increase for the green and blue rays.

Having found that we get more ultra-violet rays from a lamp

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the hotter it is operated, we naturally had to take care not to overdo this and run the lamps at such a temperature that they would suffer thereby in their emission of light, particularly ultra-violet light. It is a well-known fact to everybody who has handled quartz lamps that at a certain temperature they will become almost entirely opaque to light, due to a kind of devitrification of the quartz which gives it the aspect of opaque glass. The maximum temperatures permissible so as to avoid this condition for the illuminating lamps had previously been determined. Some of our experiments for ultra-violet power were made with illuminating lamps which were operated at a somewhat lower wattage than usual. Fig. 5 shows the variation in abiotic action of such lamps, with time. The change, if any, was not very considerable.

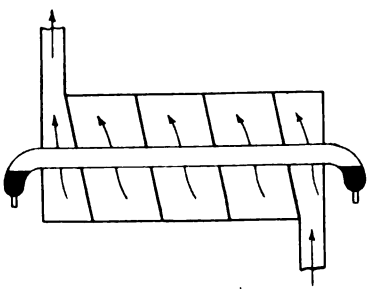

FIG. 6

On the other hand, Fig. 5 shows that lamps run hotter than illuminating lamps would lose considerably in their abiotic power with time. They evidently approach the limit at which complete opacity of the tube occurs. The problem is evidently exactly the same as for any type of incandescent lamp. We have to determine the working characteristics of the lamps to obtain the optimum of ultra-violet-time efficiency. It is probable that the electric characteristic of lamps for such work has to be chosen so as to obtain a somewhat lower temperature in the luminous part than lamps for illuminating purposes usually have.

## STERILIZING APPARATUS

The most efficient way for the mercury lamp to react upon water seems to be, *a priori*, to submerge the lamp entirely in the water which is to be sterilized, as proposed in 1906 by De Mare (Fig. 6), and tried in many experiments by Courmont and Nogier (Fig. 7). Direct contact, however, of the water with the heated lamp influences the luminous and ultra-violet efficiency of the quartz lamp to an enormous degree, as may be seen from Fig. 8. It seems to be certain, therefore, that it is better, if one wants to plunge the light source into the water, to protect the lamp from direct contact with the water, and this system has been adopted with modern apparatus. This protection against

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direct contact can be secured by fusing over the lamp a wide quartz jacket which prevents contact of the light-giving portion of the lamp, with the water as shown in Fig. 9.

Difficulties, however, arose in the manufacture of such jacketed

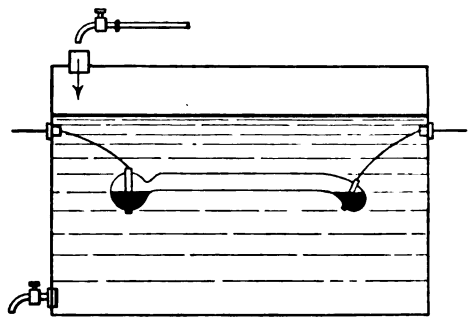

FIG. 7

lamps and it was found advisable to construct the apparatus in such a way that the lamp was removable from the protective jacket, as shown with the so-called pistol lamps, Fig. 10, allowing, nevertheless, all the light to enter the water (Fig. 11). Another method is to let the water circulate in such a way around the lamp

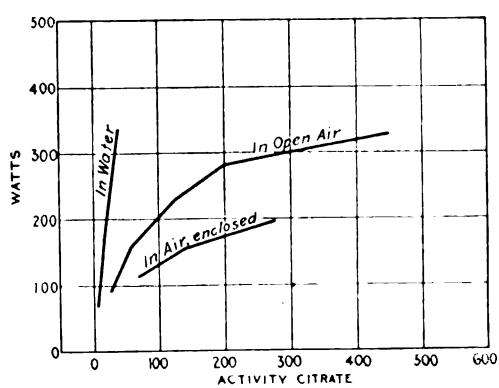


FIG. 8

that it would not come into contact with it, receiving nevertheless practically all the rays emitted by the lamp, as shown in Figs. 12 and 13.

Where it is more a question of convenience and less a question of efficiency the simplest method is evidently to place the lamp

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above the water but as close as possible to its surface. (Fig. 14.) Figs. 15 and 16 show such arrangements which have been used on a large scale. Unfortunately, reflectors placed above such lamps have a low efficiency in reflection of ultra-violet rays. It

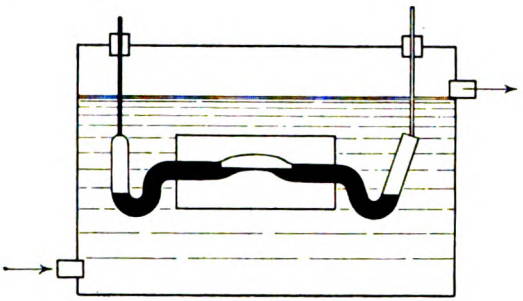

FIG. 9

may therefore be said that with such apparatus hardly half the rays of the lamp will enter into the water.

### CONTACT OF THE RAYS WITH THE GERMS

Different germs have different sensibilities to the ultra-violet rays, as may be seen from Fig. 17. The ones of greatest interest

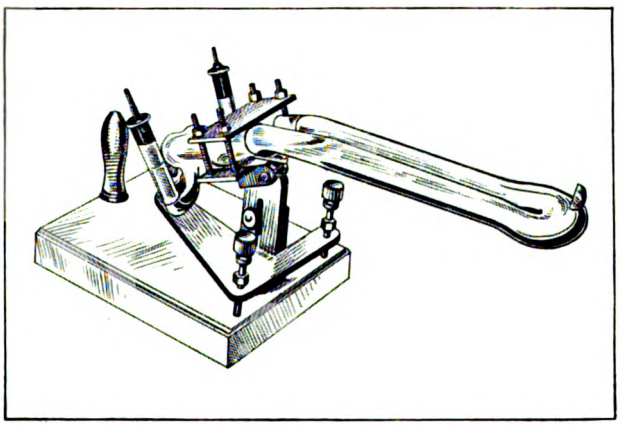

FIG. 10

to us are the water bacteria and we find that they are killed in as short a time as 1/20 second, at a distance one to two centimeters from the powerful ultra-violet ray lamps. Water being practically as transparent as air to the ultra-violet rays, we are therefore certain that if a germ floats in the water it will be annihilated by

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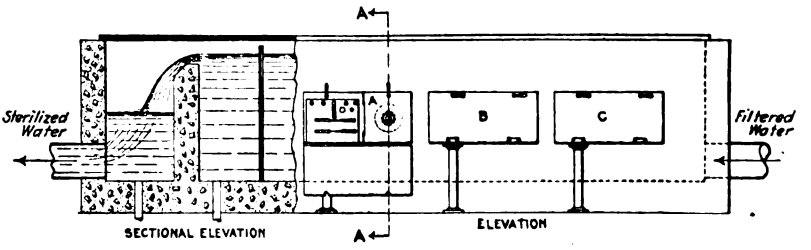


FIG. 11a

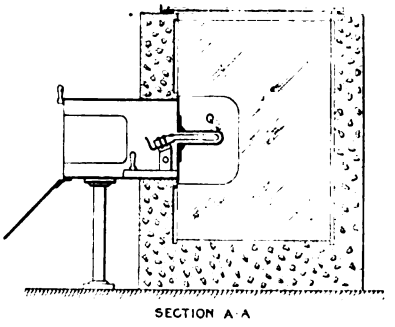


FIG. 11b

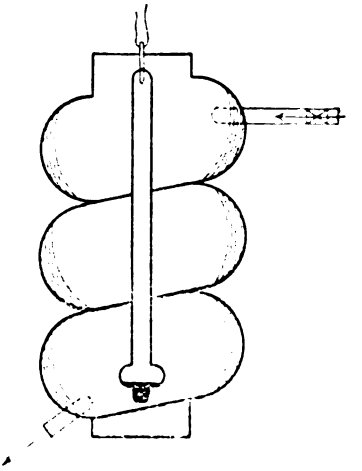

FIG. 13

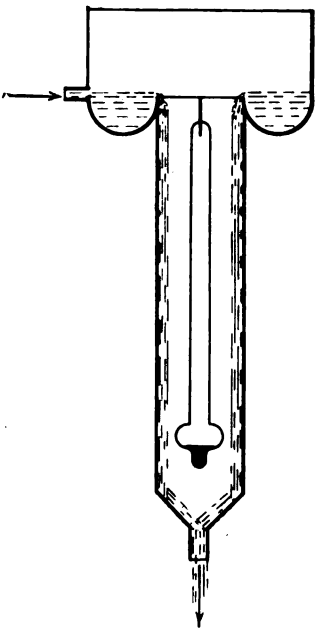

FIG. 12

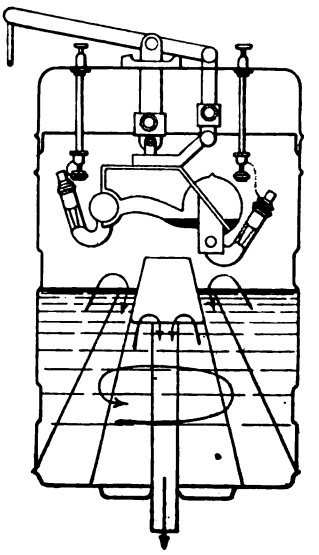

FIG. 15

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getting into the illuminated zone, the condition for this being that no suspended matter is contained in the water which would form a shield for the germ.

Water for this sterilization has, therefore, in most cases to be

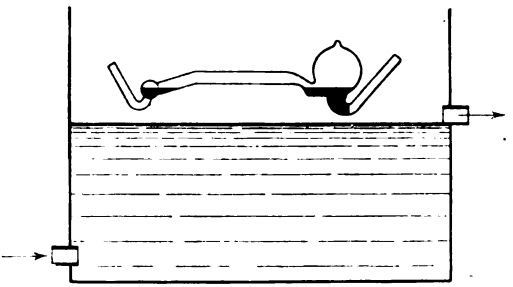

FIG. 14

filtered before being submitted to the sterilizing action of the rays. However, even very good filters will allow some microscopic matter to pass. It is much more effective, as shown by experiments, to stir up such water while it is going through the il-

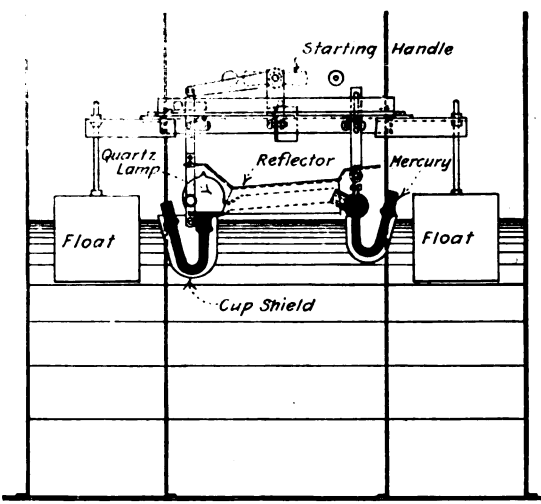


FIG. 16

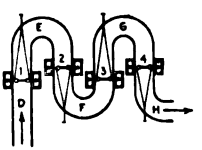


FIG 16A

luminated zone so as to turn over and over any particles which otherwise might allow microbes to pass by under cover. The baffle arrangements as shown in Figs. 11, 15 and 16 are built in for this purpose of stirring up the water. For the same reason,

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also, it is best to pass the water through several illuminated zones, which can easily be done by leading the water several times towards the same source of light (Fig. 15), or by passing it successively under several sources of light, as shown in Figs. 11 and 16.

## Typical Installations

The largest unit ever built (Fig. 18) was set up about two years ago in the city of Luneville, France, to sterilize the city water supply. It consists of a flume into the sides of which ten 500-volt pistol lamp equipments are inserted. These equipments consist of metal boxes for the starting of the lamps (the latest types of them contain also the rheostats). The boxes are equipped on the inside with a stuffing box arrangement holding the quartz protective tube which protrudes into the water.

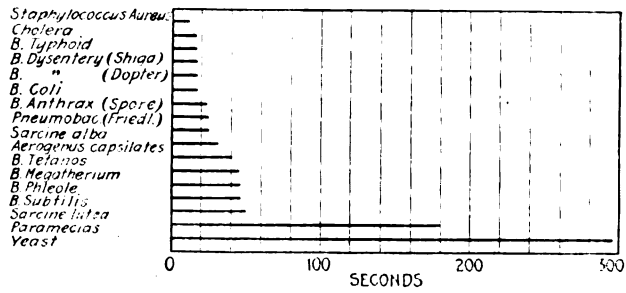


Fig. 17

The lamps are lit in the starting boxes and then their luminous parts are inserted into the protective tubes, so that the light emitted from the lamp enters the water.

The raw water fed into this plant comes from the Meurthe river and contains sometimes as high as 60,000 germs per cu. cm. It is clarified by a series of roughing filters and one filter. After this it is physically in fairly good condition, being very poor in suspended matter, but having from time to time fairly deep color (up to 45 U. S. standard) in solution. The germ contents are sometimes as high as 1000 per cu. cm. in this water. It is then passed through the sterilizing unit described above, coming under the influence of the light from one to two minutes altogether, according to the number of lamps running. This number (sometimes only 4) depends on the physical condition of the water, which is easily observed. The bacteriological tests of

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the water when leaving the sterilizer rarely show more than 10 germs per cu. cm. and are often zero. Bacterium coli is always eliminated. Not only are the bacteriological tests satisfactory; the health of the community has improved considerably. Typhoid used to cause from 70 to 160 deaths annually; it is now practically eliminated, there being no cases at all this year.

Another typical installation was made in New York lately for the purification of the water of a swimming pool, which is naturally exposed to continuous pollution from the bathers. The water in this case is circulated continually through a filter to take out suspended matter and then it passes through the ultra-violet ray sterilizer. This apparatus is similar to the Luneville unit except for its size, as it contains only two 220-

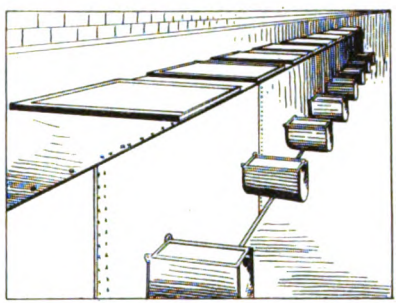

FIG. 18

volt pistol lamps. It is rated at 175,000 gallons capacity per day. Tests at the outlet of the sterilizer show only a few germs, and tests of the water going to the purifying apparatus have improved from 6000 germs per cu. cm. to about 350 germs per cu. cm. since the introduction of the ultra-violet ray apparatus.

### CONSUMPTION OF ELECTRIC ENERGY

The smallest lamp used in the above apparatus operates at 110 volts with two amperes. The largest made so far is for 500 volts, 2.5 amperes. The largest apparatus built contains ten of the last-mentioned lamps. The power consumption in such a case, with a very large safety coefficient for the sterilization, is between 50 and 130 kw-hr. per million gallons of water. This amount of power is evidently not very great but it will

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always do something to smooth out the load curve of a power station, as, in most cases, such apparatus will be operated continuously. Many installations of this kind have been made in Europe for both small and large water works, and they are operating very successfully. Their simplicity and rapidity of action are highly satisfactory.

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# TOLL TELEPHONE TRAFFIC

## An Experimental Study of the Relationship between Circuit Loads and Delay to Traffic.

BY FRANK F. FOWLE

ABSTRACT OF PAPER

Experiments are described to determine the relationship between telephone circuit loads and the corresponding delay to traffic. The operating methods employed and the number of circuits available determine in general the number of messages per day which can be handled over a single toll circuit. The average delay to traffic obviously depends upon the number of messages per circuit per day, or the circuit loads. With a given load factor, increase in the circuit loads will increase the average delay to traffic. At the same time the revenue per circuit mile will correspondingly increase. The practical limit, however, is approached when the delays to traffic reach a point where the service is unsatisfactory. The results of the experiments described illustrate the fact that increasing circuit loads increase the delay to traffic, and vice versa. The revenue per circuit mile is directly proportional to the product of the circuit load and the toll rate per minute-mile; consequently the relationship between the quality of service and the toll rate is generally obvious, assuming a certain rate of return on the plant investment.

THE NUMBER of telephone messages per day which can be handled over a single toll circuit, as is well known, depends upon several considerations. Chief among these are the operating method employed and the number of circuits required to handle the total traffic between the given terminals. A complete dissertation upon toll operating methods would extend far beyond the scope of the present paper, and only the simplest or fundamental methods will be mentioned. The earliest method, and one still used to a great extent in handling small volumes of traffic, is the direct ring-down, in-and-out ticket (or two-ticket) method. In this method the operators signal each other direct, over the talking or message circuit, by ringing in the usual manner; the outward operator makes a complete ticket, and times and supervises the connection; the inward operator also makes a duplicate ticket, but does not time the connection. This method has been materially improved by



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eliminating the inward ticket, and by having the outward operator deal directly with the called party at the destination instead of through the intermediary of an inward operator who repeats the details back to the outward operator. In some cases the last method has been modified to the extent of having the inward operator make a memorandum ticket or so-called skeleton ticket, for checking purposes, but this is usually eliminated if possible. Other operating methods, special in their nature, apply when the volume of traffic is very large, but do not come within the scope of the present discussion.

It is not necessary to dwell at length upon the fact that the number of messages per day, per circuit, increases (other factors being the same) as the volume of traffic and the number of circuits operated in one group to handle it also increase. That is, the circuit efficiency increases as the number of circuits or trunks in a group increases, and more messages per circuit, per day, can be handled in a large group than a small one, with the same average delay to traffic and equal load factors.

The effects of the operating method and the size of the trunk group upon the circuit loads (messages per circuit per day) are usually discussed from the standpoint of a certain fixed quality of service, that is, a certain average delay to traffic which is maintained as a standard. This period of delay is generally accepted as the interval from the time the calling subscriber gives his call to the recording operator, until the line operator establishes the connection or returns a definite report in regard to the called party. It seems fairly obvious, however, that there must be some definite relation between the circuit loads and the average delay to traffic. In other words, with a constant load factor, the effect of increasing the circuit loads will be to increase the average delay to traffic; at the same time the toll revenue per circuit-mile will correspondingly increase. Naturally a limit will be approached when the traffic is delayed to such an extent that subscribers complain of the delay and a loss of business is threatened.

This relationship between circuit loads (traffic density per circuit) and average delay to traffic, if not already clear, can be illustrated by a simple analogy with railway transportation. Given a fixed volume of traffic (passenger or freight) to be transported, the delays in traffic movement will be least when the train service is as frequent as it is possible to arrange it; but unless the volume of traffic is very large, the train loads may

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not be large enough to produce an adequate net revenue per train mile. In order to increase the train loads to a point where the operating revenue per train mile will exceed the cost by a reasonably profitable margin, it will perhaps be necessary to resort to less frequent train service. This implies a longer average interval between trains, and consequently a longer average period of waiting or delay before the traffic is moved. The parallels in the analogy are between the number of trains and the number of toll circuits, between train loads and circuit loads, and between delays to railway traffic and to toll traffic, a fixed volume of traffic in each case being assumed.

The general problem is therefore one of the highest commercial importance, since it is perfectly obvious that under a given schedule of toll rates there is a certain standard of service which cannot be exceeded without the sacrifice of profits, and

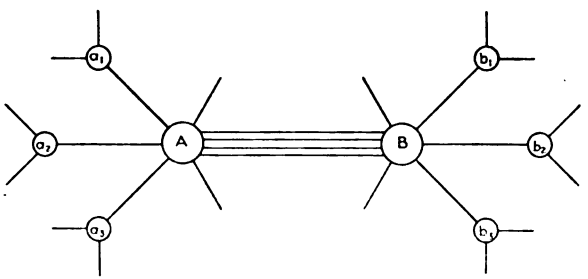


FIG. 1—PORTION OF A TOLL SYSTEM, TOLL CENTERS AT A AND B

the faster the service as a whole the higher must be the rates for the same percentage of profit. It is not at all the intent in this paper to reach any conclusions as to the commercial side of the question, but simply to present certain experimental data bearing on the general principle.

## LAYOUT OF EXPERIMENTAL CIRCUITS

The general layout of the toll lines used in the experiments here described is shown in Fig. 1. The group of circuits upon which the experiments were made extended between $A$ and $B$, the latter representing two toll offices, or toll centers. The greater portion of the traffic either originated at $A$ and terminated at $B$ or vice versa. The remainder of the traffic was of a through (instead of terminal) character, necessitating the use of tandem circuits. For example, a call originating at $A$ and destined for $b_2$ or some point beyond, would have to be switched at $B$; in some cases the call would be passed to the operator at $B$, who

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would take the details and record them on a through ticket, and then pass the call to $b_2$, while in other cases the operator at $B$ would connect the line through to $b_2$ and the operator at $A$ would pass the call to the operator at $b_2$. The entire traffic passing over the group of circuits between $A$ and $B$ can be classified as follows, for convenience.

TABLE I

CLASSIFICATION OF TRAFFIC OVER GROUP OF CIRCUITS BETWEEN $A$ AND $B$ IN FIG. 1.

| $A$ to $B$<br>$B$ to $A$ | Class 1 |
|---|---|
| $A$ to $b_1$ or $b_2$ or $b_3$<br>$B$ to $a_1$ or $a_2$ or $a_3$ | Class 2 |
| $a_1$ or $a_2$ or $a_3$ to $B$<br>$b_1$ or $b_2$ or $b_3$ to $A$ | Class 3 |
| $a_1$ or $a_2$ or $a_3$ to $b_1$ or $b_2$ or $b_3$<br>$b_1$ or $_2$, or $b_3$ to $a_1$ or $a_2$ or $a_3$ | Class 4 |

Normally there were six circuits between $A$ and $B$; this number was reduced successively to five and then to four, operating for several days under each of the last two conditions in order to secure reliable test data. A study of the traffic was then made from the tickets, excluding any days such as Sunday or Saturday when the traffic is not normal, and also excluding any days when there was any wire trouble on any of the circuits in the group. Of course it should be understood that the through traffic did not necessarily originate or terminate at the first office beyond $A$ or $B$, but in some cases involved offices reached by two or more switches.

## SUMMARIES OF TEST DATA

The operating method employed in handling the terminal business (class 1 traffic) between $A$ and $B$ (Fig. 1) was the direct ring-down, single-ticket method, while all other traffic was handled by the double-ticket method. The through business was handled in some instances by means of relays, or through tickets at the switching point, and in other cases by straight switches (no ticket).

The summary of results is presented in Table II. Recapitulating, the class 1 traffic is the terminal business between $A$

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TABLE II

SUMMARY OF AVERAGE DAILY TRAFFIC OVER THE GROUP OF TOLL CIRCUITS BETWEEN *A* AND *B* (FIG. 1.)

| Number of circuits in use | Class 1 traffic | | Class 2 traffic | | Class 3 traffic | | | Class 4 traffic | | | Total number of messages (2) switches taken as 1 message | Number of messages per circuit | Revenue per circuit mile | Number of day's business averaged |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Relayed | | Switched | Relayed | | Switched | | | | |
| | Number of messages | Average delay (min.) | Number of messages | Average delay (min.) | Number of messages | Average delay (min.) | Number of switches | Number of messages | Average delay (min.) | Number of switches | | | | |
| 6 | 124 | 7.0 | 19 | 17. | 4 | 9.2 | 25 | 3 | 14. | 2. | 164 | 27.3 | $.187 | 3 |
| 5 | 144 | 12.2 | 22 | 25. | 8 | 5.8 | 41 | 3 | 20. | 2. | 198 | 39.6 | .255 | 3 |
| 4 | 140 | 21.1 | 17 | 30 | 13 | 21. | 43 | 2 | 6. | 1. | 193 | 48.2 | .314 | 2 |

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and $B$ (Fig. 1), the class 2 traffic is the through business originating at $A$ and $B$, the class 3 traffic is the through business terminating at $A$ and $B$, and the class 4 traffic is the through business to and from points beyond $A$ and $B$ but passing over the circuits between the latter. There was no simple way of determining whether each through switch at $A$ and $B$ was set up for the transmission of a message, but in general the number of switches exceeds the corresponding number of messages and it was arbitrarily assumed that there was one message for every two switches. The average duration of a message was approximately four minutes. The rate schedule in force was the same throughout each 24-hour period.

Table III shows a summary of lost and delayed business,

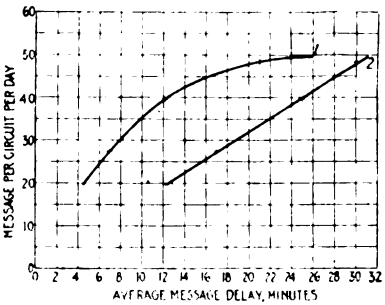


FIG. 2—CURVES SHOWING THE RELATIONSHIP BETWEEN CIRCUIT LOADS AND AVERAGE DELAY TO TRAFFIC
Curve (1) for terminal business.
Curve (2) for originating through business.

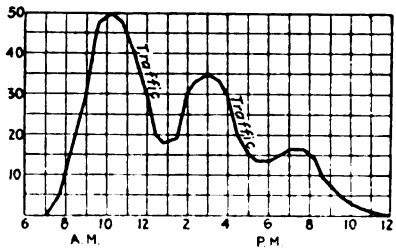


FIG. 3—TYPICAL LOAD CURVE OF TOLL TRAFFIC

for the same periods as represented in Table II. In all cases the traffic figures represent one day's business, being an average of several day's business as indicated in the last column in Table II.

## DISCUSSION OF RESULTS

The relationship between the average delay to terminal business (class 1 traffic) and the circuit loads is plotted in curve (1), Fig. 2; the similar relationship for the originating through business (class 2 traffic) is plotted in curve (2), Fig. 2. The underlying data is taken from Table II. These curves bring out forcibly the general conclusion of the paper, namely, that increasing circuit loads are accompanied by increased average delay to traffic. For example, taking the terminal (class 1) traffic, five-minute service corresponds to a circuit load of 21

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messages per circuit per day, in a group of about 8 circuits; six-minute service corresponds to a circuit load of 24 messages per circuit per day, in a group of about 7 circuits; seven-minute service corresponds to a load of about 27 messages, eight-minute service to 30 messages, ten-minute service to 35 messages, etc. The following Table IV was prepared in this manner from curve (1), Fig. 2; this of course is based primarily on handling a substantially constant volume of traffic.

TABLE III

SUMMARY OF LOST AND DELAYED BUSINESS.

| Number of circuits in use | Per cent of originating calls (A and B) lost | Number of calls delayed by "no circuit" conditions | Average no-circuit delay, on delayed calls (min.) | Number of calls lost on account of "no circuit" conditions |
|---|---|---|---|---|
| 6 | 18% | 25 | 11.8 | None |
| 5 | 17% | 62 | 12.9 | 1 |
| 4 | 21% | 99 | 16.9 | 1 |

TABLE IV

CIRCUIT LOADS FOR VARIOUS GRADES OF SERVICE WITH CONSTANT VOLUME OF TRAFFIC AND A GROUP OF 4 TO 8 CIRCUITS

| Average delay to terminal traffic (min). | Circuit loads in total messages per circuit per day |
|---|---|
| 5 | 21 |
| 6 | 24 |
| 7 | 27 |
| 8 | 30 |
| 9 | 33 |
| 10 | 35 |
| 11 | 37 |
| 12 | 39 |
| 13 | 41 |
| 14 | 42 |
| 15 | 44 |

The volume of class 3 traffic, Table II, is so small that the data on average delay are unreliable. This is more obvious by reference to a typical load curve, Fig. 3. Evidently there is a large probability that these relatively few class 3 messages were handled during some other period than the peak, or the "busy hour;" and in such case the delay would be less, owing to lighter loads on the circuits. The same is true of class 4 traffic. The daily load factor was in the vicinity of 30 per cent.

The delay to originating through business (class 2 traffic), destined to scattered points to which the business did not justify

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individual direct circuits, is shown in curve (2), Fig. 2. Of course this delay can be minimized by eliminating relay tickets at switching points and substituting straight switches.

The use of averages, particularly in reference to the delays to traffic, does not convey complete information as to the character of service, since some of the calls will inevitably be delayed longer than the average, and others less. In order to bring out fully the quality or speed of toll service it is desirable to resort to curves of the type shown in Fig. 4. These curves show the percentage of calls handled with a given delay, or less, and therefore reveal the extremes. The three curves there shown give in more detail the grade of service obtained during

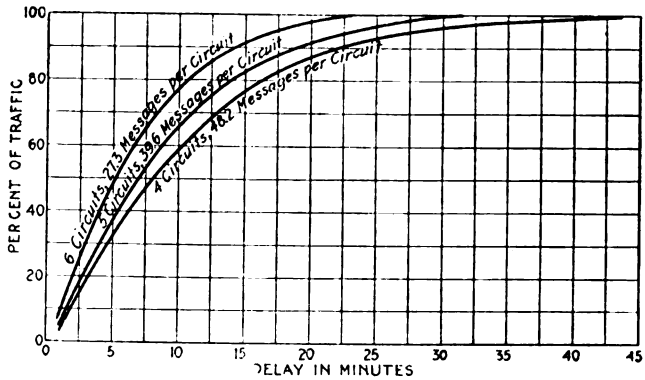


FIG. 4—PERCENTAGE OF TERMINAL TRAFFIC HANDLED WITHIN A GIVEN INTERVAL OR LESS

the tests whose results are recorded in Table II. Each of these curves applies only to the terminal business, or class 1 traffic; the average delay in each case may be found in Table II.

The results given in the paper, although they apply specifically to conditions which do not differ widely from those described, nevertheless serve to illustrate the fundamental principle that increasing circuit loads increase the delay to service, and vice versa. The revenue per circuit-mile per day, or per annum, is directly proportional to the product of the circuit load and the toll rate per minute-mile. Consequently the relationship between the quality of service and the toll rate schedule is in general an obvious one, assuming of course that a certain fixed percentage of return on the plant investment is maintained in all cases.

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*To be presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 26, 1914, under the auspices of the Telegraphy and Telephony Committee.*

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# A HIGH-SPEED PRINTING TELEGRAPH SYSTEM

BY CARL KINSLEY

ABSTRACT OF PAPER

The paper describes a system of high-speed printing telegraphy devised by the author, a prominent feature of which is the simplicity of the apparatus and its operation. The author briefly mentions a number of high-speed systems which have been tested by the operating companies, none of which have completely fulfilled all the requirements for accuracy, rapidity and low cost which are desirable for commercial work.

The system described is operated in connection with a commercial typewriter to which a punch is connected which perforates a half-inch strip of paper with groups of holes distinctly spaced in five rows, each group representing a letter. The punched strip of paper is then sent through the transmitter so that the holes pass under five wire brushes. Batteries of either polarity are thus connected between the earth and either one of a pair of conductors, or batteries of different potential can also be used. At the receiver there are five elements which are separately controlled and these elements make an autographic record by means of a local battery on a moving sensitized paper whenever they touch the surface. The apparatus which is comparatively simple is illustrated and described in detail. On the basis of duplex working and the use of two wires the operating speed is 650 words per minute over a 375-mile line.

THE RATE of increase in the amount of business transacted by telegraph has been most marked during the past few years. The extension of the network of telephone wires and their universal use in local business has seemingly stimulated the desire for a formal method of inter-communication which is more rapid than the mails.

The operating companies have responded as fully as they could, with the means available, to the public demand for a more rapid, accurate and inexpensive service. They have carefully tested many systems of telegraphic transmission that have been presented to them. None of the systems, however, have fulfilled all of the requirements for accuracy in the transmission of the messages, rapidity of operation from the receipt of the message to its final delivery, and low cost; the latter includes,



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in particular, interest on invested capital, depreciation of telegraphic apparatus and lines, maintenance of plant and cost of operation.

It is impossible to adequately mention in the brief space available the telegraph systems which have already been tried, some of which have by no means been discarded. Among them the following may be of particular interest.

The Rowland multiplex printing telegraph system[1] has enjoyed a limited use in Italy and was experimentally operated on commercial business for a considerable time in this country. On the basis of eight machines operating simultaneously over two wires a speed of 400 words per minute could be obtained.

The Murray printing telegraph[2] was given a commercial test in America in 1900 and later taken to England where it was developed to a much more perfect state in the laboratories of British P. O. Department. It has recently been given a month's trial in this country. Used duplex with four machines working on the two-wire circuit and with eight automatic translators, a speed of 400 words per minute can be reached.

The Baudot printing telegraph[3] has been extensively used in France and India, while recently its use has been spreading to Great Britain, where certain improvements have been added. On the basis of duplex working, and using two wires, 160 words per minute can be transmitted.

The Siemens-Halske rapid printing telegraph system[4] has been remodelled from the system developed and extensively tested about 1903, which used a photographic process of recording. In its present form it has been successfully used on certain German lines and is being tried over three or four different circuits at the present time. It seems to be specially suited for underground

1. G. Robichon, "Le Telegraphie Rowland," *Journal Telegraphique*, Jan. 25, 1901 and Feb. 25, 1901.

Potts; *The Rowland Telegraph System*, A. I. E. E. Proc., April, 1907.

2. Vansize; *A New Page Printing Telegraph*, A. I. E. E. Proc., Jan. 25, 1901.

Murray; "Practical Aspects of Printing Telegraphy" Inst. Elec. Eng. *Jour.* v. 47, p. 450, 1911. See also *Electrician*, May 5 and 12, 1911.

3. "D'Appareils Baudot," Poulaine and Faivre, Paris, 1906.

Williams; "The Baudot Telegraph System in India," *Electrician*, Mch. 22, 1907.

4. Franke, "Der neue Schnelltelegraph der Siemens und Halske," *Elektrotechn. Zeitschr.*, Sept. 25, Oct. 2 and 9, 1913.

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cable work, as the speed of each instrument is low and the required perfect control of both synchronism and phase of the transmitter and receiver is then not affected by atmospheric conditions. The necessity for an entire absence of disturbance can be comprehended when it is noted that many letters require the operation of seven relays to switch circuits in the through line in preparation for each record. On the basis of duplex working and the use of two wires a speed of 400 words per minute is obtainable. This is only half as fast as the early form which required the developing, fixing, washing and drying of the record of the receiving message and thus produced a condition at the receiving end which was considered uncommercial.

The Pollak-Virag writing telegraph system,[5] unlike any of the preceding, does not require synchronism between transmitter and receiver. The received message, however, is photographically recorded on a sheet, which process entails expense and delay in handling the message. It was given an extensive commercial test over German lines and also was exhibited in England and in this country in 1899. On the same basis as that used in the tests of the previous systems the Pollak-Virag telegraph operated at 650 words per minute.

The system about to be described does not employ synchronism between transmitter and receiver, there are no relays used in the operation at either end of the line, only one instrument is employed, and the message is received ready for distribution. On the same basis of computation used in the above systems the speed of operation of the author's printing telegraph is 650 words per minute over a 375-mile (603.5 km.) line.

## Plan of Operation

The method employed is direct throughout and the transmitting and recording parts are capable of such adjustment that the speed of operation is limited only by the speed of the line. The mode of operation is as follows:

By means of a punch which is connected to a commercial typewriter a half-in. (1.27-cm.) strip of paper is punched with a

5. "Der Schnelltelegraph von Pollak und Virag" *Elektrotechn. Zeitschr*, Oct. 11, 1900.

"Recent Improvements of the Pollak-Virag Writing Telegraph," *Electrician*, July 3, 1903. "Telegraphie Rapide Systeme Pollak et Virag," *Ecl. Electr.*, Jan. 5, 1907.

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series of groupings of holes distinctively spaced in five rows, each group representing a letter. The punched strip of paper is then sent through the transmitter so that the holes pass under five wire brushes. Batteries of either polarity are thereby connected between the earth and either one of a pair of conductors. Batteries of different potential can also be used, and in one case that is done, making five different transmitting impulses. Fig. 1 shows the wiring connections, a representative piece of transmitting tape, the printing elements and a section of the record.

At the receiver there are five elements which are separately controlled except that No. 3 which needs only the normal current also operated when the strong current needed to operate No. 5 is received.

The printing is accomplished by subdividing the alphabet

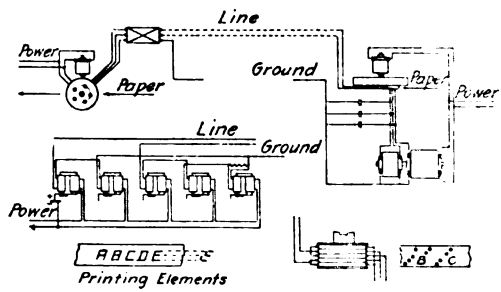


FIG. 1

into four independent elements and a fifth which whenever, used, accompanies one of the others. These elements then make an autographic record by means of a local battery, on a moving sensitized paper whenever they touch the surface. It is merely necessary to have them operated in the proper sequence and with the desired interval in order to obtain any letter or figure of the alphabet.

## PHOTOGRAPHS OF COMPLETE APPARATUS

Fig. 2 shows the punch for preparing the transmitting tape. A commercial typewriter is set on the punch base and the operation of preparing an office copy of the message also punches the transmitting tape. The depression of the digit bar sets the proper punch combination, then closes the circuit of an electro-

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magnet which completes the operation of punching and spacing the transmitting tape. The tape is then rolled up ready for use on the transmitter. As many punching machines can be used at the same time as may be needed to supply the transmitter with a sufficient number of rolls of prepared messages.

Fig. 3 illustrates the automatic transmitter. The roll of paper carrying the message is driven under the wire brushes which drop through the holes and make contact with the underlying rings, five in number. These rings are slowly rotating, driven by the paper friction, so as to insure a continually changing point of contact. No trouble at all has been experienced with faulty contacts. No speed control has yet been used on the driving motor as it has not been found necessary to have any exact speed of transmission.

Fig. 4 shows the method of construction of the artificial line which needs more than a passing notice. It is made of a great many sections all connected in series. Each section consists of two tinfoil grids, separated by wax paper with solid tinfoil sheets outside of them, also separated from the grids with waxed paper. The solid sheets are $6\frac{1}{2}$ in. by 9 in. (16.5 cm. by 22.8 cm.) and completely cover the grids, which are superimposed. There is thus complete distribution of the capacity and resistance of the two parts of the circuit with respect to each other as well as with respect to the ground, while each section is shielded from the neighboring sections. The total capacity from either line to ground, measured with an a-c. pure sine wave of 120 periods per sec. is 4.05 microfarads. The total resistance of each line is 747 ohms, while the leakage resistance due to dielectric absorption is $2 \times 10^4$ ohms. There is no appreciable self-induction. On the basis of an open wire circuit having a conductor 0.43 cm. in diameter, the capacity and resistance relation would make the artificial line equivalent to a circuit 375 miles (603.5 km.) long.[6] Since the open wire line has also distributed self-induction, the current at the distant end of the actual line would be greater than that at the end of the artificial line, if the impressed e.m.f. were the same. The equivalent length of actual line might be calculated in another way on the basis of an alternating current of equivalent frequency. When transmitting messages at the rate of 650 words per min.

6. NOTE—The above equivalence is obtained by interpolation in the table on p. 256 of "The Propagation of Electric Currents," J. A. Fleming.

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the actual duration of an impulse is 1/720 sec. This would be equivalent to a frequency of 360 periods per sec.

$$\text{Assume } I_r = \frac{V_s}{Z_0} \operatorname{cosech} Pl \tag{1}$$

$$\text{Where } Z_0 = \text{initial sending end impedance} = \frac{\sqrt{r + jx}}{\sqrt{g + jb}} \tag{2}$$

$$\text{and } P = \text{propagation constant} =$$

$$\alpha + j\beta = \sqrt{r + jx}\,\sqrt{g + jb} \tag{3}$$

$r, x, g$ and $b$ are respectively the resistance, reactance, onductance and susceptance per mile.

$I_r$ and $V_s$ are the current at receiving end and impressed e.m.f. at sending end.[7] With the same $V_s$ the $I_r$ will be the same in an artificial line and actual open wire line if the length of the line, $l$, is 635 miles (1021 km.).

If the actual open line, however, is of No. 8 B. & S. gage then with the same impressed e.m.f. the current at the end of 375 miles will be the same as at the end of the artificial line. The length of the open line equivalent to the artificial line can be conservatively placed at 375 miles. The oscillograph record shown in Fig. 7 gives the current distortion, due to the long line, which is found in this case.

Fig.5 shows the receiver of the author's printing telegraph system and Fig. 6 is another view of it with the head lifted from the tape to display the printing elements. It uses two local circuits; one energizes the magnetic circuit which normally holds the printing members off of the recording surface and polarizes them. The other is in series with a resistance and has its positive terminal connected to the receiver elements which are here also the printing members while the negative terminal is connected to the slightly moistened tape. A ferrocyanide of potassium solution and iron tips to the receiver elements have been found to be cheap and satisfactory. The line circuits are connected to the receiving spools and temporarily change the magnetic flux as

7. NOTE—See page 84, Fleming, *loc. cit.*

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FIG. 2 [KINSLEY]

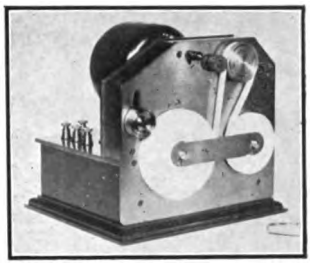

FIG. 3 [KINSLEY]

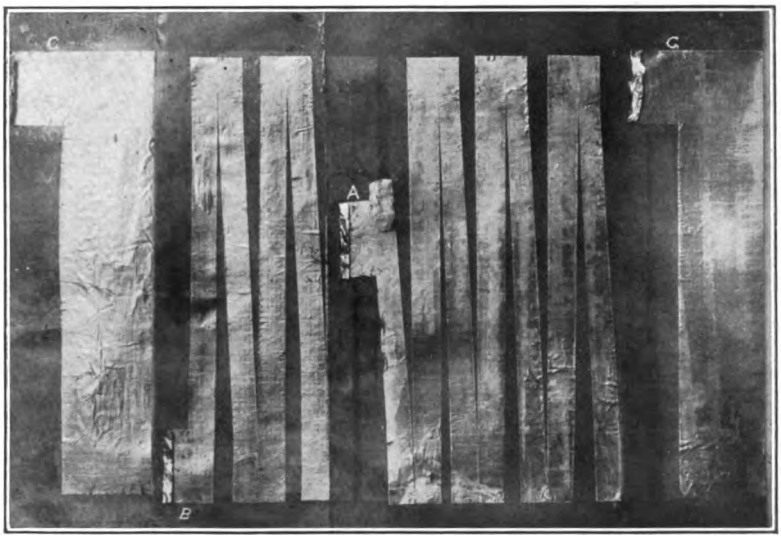


FIG. 4 [KINSLEY]

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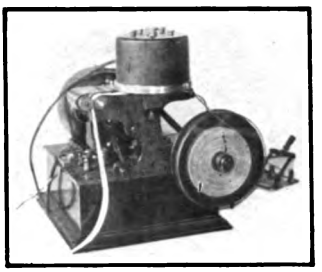

FIG. 5 [KINSLEY]

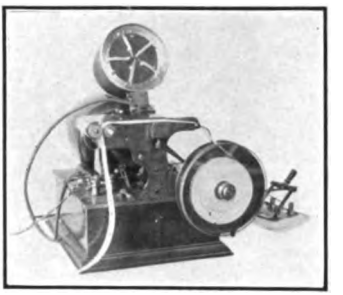

FIG. 6 [KINSLEY]

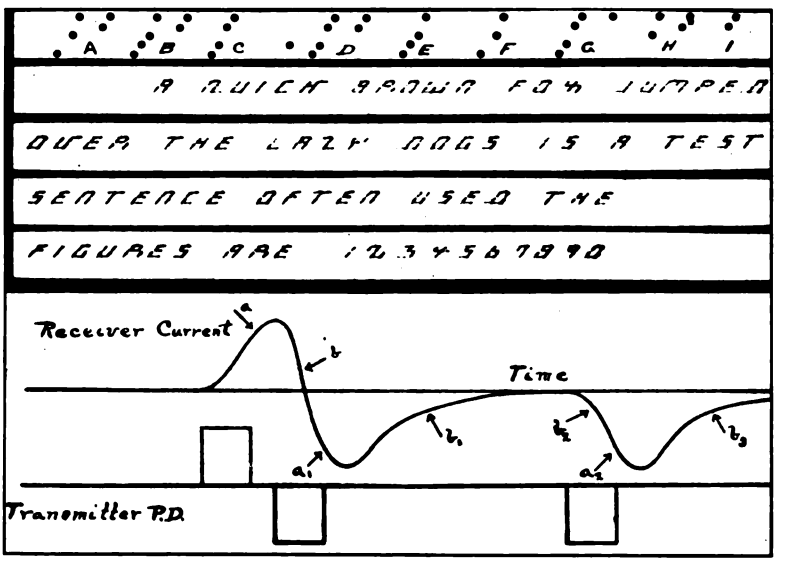


FIG. 7 [KINSLEY]

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the signaling currents are received. It is found to be desirable to use various magnetic fluxes in the different circuits but in every case the magnetic density is not large when the parts of the magnetic circuit are proportioned as in this receiver.

The five elements are mounted on a circular frame so that the printing faces nestle closely together and form the pattern already shown in Fig. 1. This pattern is only one of several which have been tested. The form of the alphabet produced by it seems to be entirely satisfactory. A sixth element could be added if greater perfection were desired while an alphabet of four elements which was thoroughly tried out was found to be legible to most people, but vastly inferior in appearance and doubtful of acceptance by the public. A sample of the transmitting tape and of the message as received is shown in the Fig. 7, although the dark blue record on a slightly tinted background is a difficult object to reproduce photographically, and it is impossible to do justice to the original. The reproduction serves, however, to show the forms of all of the letters and figures as received over the whole of the artificial line, whose constants have been given, at a rate of 650 words per minute.

## Operation of the Receiver Elements

The receiver is astonishingly consistent in its operation and it would probably be of interest to consider its functioning more in detail. The adjustment of the position of the core of a receiving magnet is accurately made by means of a reducing gear, all lost motion being avoided by the use of a stiff spring. After adjustment the receiver can be operated for a long time without any further attention. In one case, over four months elapsed without touching an adjustment screw, during which time it gave perfect service, then a break in the circuit made a repair and readjustment necessary. When a signaling current is received it will further magnetize the receiving magnet of one section of the receiver and reduce the magnetization of the one connected in series with it. The magnetization due to the local current lifts the receiver element from the paper and holds it against the core of the receiver magnet. When the signaling current slightly reduces the pull on the receiver element it is released, and the spring causes it to strike the paper, leaving its record, and then to rebound when it is again caught by the local magnetic curcuit and held, ready for another release by the signaling current. The local current therefore does the work of distorting the spring

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and the signaling current merely supplies enough energy to release and to allow the stored up energy in the spring to become effective. The receiving element has a flat spring rigidly attached to the core of the magnet which is energized by the local current. The natural period of the printing element can be made whatever is desired by varying the thickness or width of the spring and the size or location of the attached armature. The natural period of the receiving element should lie between rather sharply defined limits. Its period should be sufficiently long so that the signaling current has passed and the magnetizing current is again the controlling quality before it returns to its resting position; and the period should be short enough so that the receiving element is back at rest before amother signaling current intended to operate it is received.

Let us assume that the transmitter connects batteries directly between a line and the ground either with or without the condensers which are of service only when the source has large self-induction. Fig. 7 shows the current at the end of a 375-mile artificial line, due to the impressed constant e.m.f., as obtained by photographing oscillograph curves at both transmitter and receiver. The current is such as would be used in the vertical lines of a *G*. If we consider the negative current, which releases the element making the lower half of the vertical line for its two strokes, it can be seen that the natural period of the element should lie between definite limits. Since the element is more strongly held in place while the positive current impulse is on the line but is released when the negative current reaches $a_1$ and held again when the current is not more than $b_1$ then the period of the printing element should be longer than time between $a_1$ and $b_1$ but shorter than the time between $a_1$ and $b_2$. There is one exception that is of minor importance since it is desirable to avoid synchronism in general, that is if the natural period is exactly as long as the interval from $a_1$ to $a_2$ then the second release will come at the proper time. If the natural period has a value such that the element returns to its initial position at any time between $b_2$ and $b_3$, except at $a_2$, then the resulting stroke will be given at the wrong time. This may not be so far wrong as to lead to illegibility, but will obviously give an imperfect result. The natural period used with this instrument as now adjusted lies half way between $a_1$ and $a_2$. This high natural period allowed the use of the " " marks which are not considered a necessary part of the telegraph alphabet.

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Hundreds of oscillograph records have been made, and it can be stated positively that with the present circuit and apparatus design no combination of currents can occur which will cause errors in the record. It is evident that a sufficient increase of speed or an increase in the length of the line without an appropriate reduction of speed will produce an inoperative condition, but as previously stated, the speed attainable is limited by the line and not by the terminal instruments.

The elements most frequently used are the two which combined make a straight upright line. This is produced, as already shown in Fig. 7, by connecting the battery to the line for 1/720 of a second and then reversing it for the same interval. This can be considered as a part of a periodic wave having the equation[8]

$$V_s = \frac{4E}{\pi} \sum_{0}^{\infty} \frac{1}{2m+1} \sin \frac{2m+1}{T} 2\pi t \qquad (4)$$

$V_s$ = potential difference at transmitter at the time $t$ counted from the time the positive potential is connected to the line.

$E$ = potential difference of battery.

If we assume that the actual transmission will be equivalent to the sum of the series as far as the terms are appreciable, using $m = 0, 1, 2, 3$, etc. It will be possible to combine the arriving waves and obtain the arrival curve from the equation computed separately for each period, *i.e.* for each value of $m$.

$$I_r = \frac{V_s}{(Z_s + Z_r) \cosh Pl + \left(\frac{Z_s Z_r}{Z_0} + Z_0\right) \sinh Pl} \qquad (5)$$

$Z_s$, $Z_r$ and $Z_0$ are the impedances of the sending and receiving apparatus and the initial sending end impedance.

$$Pl = \alpha l + j\beta l = l \sqrt{r + jx} \sqrt{g + jb}$$
$$= 2.62 \angle 44° 26' \text{ for } m = 0 \qquad (6)$$

8 The form employed is that used by Malcolm, *Electrician*, April 15, 1912, p. 916 eq. 32.

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$$Z_0 = \frac{\sqrt{r + jx}}{\sqrt{g + jb}} = 285.5 \angle 45^\circ \text{ for } m = 0 \tag{7}$$

$Z_s = 0$ when batteries are used

$$Z_r = 56 + j\,859 = 862 \angle 86^\circ\ 15' \text{ for } m = 0 \tag{8}$$

$$\text{For first harmonic, } m = 0,\ Ir = \frac{V_s}{2320 \angle 174^\circ\ 7'} \tag{9}$$

The 2d harmonic, $m = 1$, has an amplitude of only $2\frac{6}{10}$ per cent of the first, and 3d harmonic, $m = 2$, has an amplitude of only $\frac{35}{100}$ per cent of the first.

In other cases with shorter lines the harmonics up to the fifth may be appreciable but they in no way interfere with the operation of the receiver if the receiving elements are properly designed.

At the receiver, the current flow, so far as it materially affects the printing elements, is therefore a sine wave of frequency 360 periods per sec., as is apparent from an inspection of the oscillograph curves of Fig. 7.

No estimate will be made of the cost per message, but the various items which have rendered other printing telegraphs too cumbersome or expensive for general commercial use are here conspicuously absent. The whole receiving and printing part of the mechanism can be easily held in the hand or carried in one's pocket. Aside from the paper drive and the power circuits there are only five moving parts and they consist of stiff flat springs rigidly attached to the frame. The movement of each is less than 1/25 of an inch (one mm.) and there is no possibility of their getting out of order or needing adjustment. If the paper drive is started by a line impulse from the transmitter, a message could be received without the necessity of an attendant ever being present. The receiver, due to its extreme simplicity and entire absence of delicate parts, would have its first cost considerably less than that of a single sensitive relay. The cost of maintenance and operation will obviously be reduced to a minimum, since on account of its simplicity and speed the number of attendants and their individual skill will be far less than at present needed. Of the

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entire system, the most complex part as well as the most expensive is the commercial typewriter. It is not altered in any way, and if large users of the telegraph should themselves prepare the transmitting rolls the typewriters would be available at other times for general office purposes.

The widespread interest in and need for a cheaper telegraph service should undoubtedly lead to the adoption of some machine method of telegraphy which would make possible a large reduction in telegraph tolls.

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## AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

## REPORT OF THE BOARD OF DIRECTORS FOR FISCAL YEAR ENDING APRIL 30, 1914

The Board of Directors of the American Institute of Electrical Engineers presents herewith to the membership its annual report for the fiscal year ending April 30, 1914.

Only a summary of the work which has been accomplished during the year is possible in this report, but in the preparation of it a sufficient amount of detail has been given to convey a general idea of the scope and activity of the Institute. Those members desiring further information are referred to past issues of the monthly PROCEEDINGS, in which nearly all matters of importance have been given publicity in greater detail. Abstracts of the reports of many of the Institute committees, as submitted to the Board, are included herein.

The exact status of the Institute's financial affairs will be found in the statements at the end of this report, which show the finances to be in sound and satisfactory condition. The statements also contain detailed information respecting the various trust funds, assets and liabilities, and other financial data.

**Meetings of the Board.**—The Board of Directors has held 10 meeting during the year; nine at Institute headquarters in New York, and one at Cooperstown, N. Y., during the Annual Convention. In order that the membership may keep closely in touch with the administration of the Institute's affairs, a résumé of business transacted at these meetings is published each month in the Institute PROCEEDINGS. This, however, represents only a portion of the business transacted by the Board, as many important matters are considered to which publicity is not given pending their final settlement. Such matters are dealt with in subsequent issues of the PROCEEDINGS under appropriate headings.

**Conventions.**—The Annual Convention was held in Cooperstown, N. Y. June 23–27, 1913. The total registered attendance was 242, of which 171 were Institute members. Of the 71 guests, 54 were ladies. Twenty-four papers were presented at the six technical sessions. The reduction in the number of papers over the two previous years was favorably commented upon, as it afforded longer time for discussion and eliminated the necessity for parallel sessions.

The success of the first Midwinter Convention, held in New York early in 1913, led the Board to give favorable consideration to a demand for a similar convention this year, which was held at Institute headquarters February 25–27, 1914, under the auspices of the Electric Power Committee. Sixteen papers and reports on the general subject of electric power were presented, several of the reports embodying separate short papers by different authors, each devoted to some subdivision of the main



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subject. The total registered attendance was 472, of which 354 were Institute members. A subscription dinner-dance, under the joint auspices of the Institute and the Executive Committee of the Committee on Organization of the International Electrical Congress to be held in San Francisco in 1915, was the only official social function of the convention. About 350 members and guests participated in this event.

The fifth annual Pacific Coast Convention was held in Vancouver, B. C., September 9–11. The arrangements were made and admirably carried out under the auspices of the Vancouver Section. Six technical papers, relating chiefly to industries and operations of interest to engineers on the coast and in the northwest, were presented. The total attendance was 154. Vice-President Lighthipe represented the President, and presided at this meeting.

**Other Meetings.**—A meeting was held in Philadelphia, Pa., on October 13, 1913, under the auspices of the Philadelphia Section. Three papers were presented and discussed at this meeting, and the total attendance was 204.

A meeting was held in Pittsburgh, Pa., April 9–10, 1914, under the auspices of the Committee on the Use of Electricity in Mines and the Pittsburgh Section. Five papers on the application of electricity in mining were presented, and 191 members and guests attended.

A two-day meeting was held in Washington, D. C., April 24–25, 1914, in cooperation with the American Physical Society. The meeting was conducted on behalf of the Institute by the Electrophysics Committee, with the assistance of the Washington and Baltimore Sections, and the papers presented related more or less to the general subject of electrophysics. The Institute contributed five of the papers presented at the meeting.

In addition to the foregoing meetings, regular monthly meetings have also been held in New York, excepting during the summer months.

The Sections and Branches of the Institute have been exceedingly active, having held more than 500 meetings throughout the country.

During the year, President Mailloux, Honorary Secretary Pope, and Secretary Hutchinson have attended a large number of Institute and Section meetings in various parts of the country.

Future Institute meetings during the present year are being arranged for, as follows: Pittsfield, Mass., May 28–29; Annual Convention, Detroit, Mich., June 23–26, Pacific Coast Convention, Spokane, Wash., September 9–11.

**Scientific Lectures.**—The wide-spread interest shown by members and non-members in the lectures on radioactivity by Professor E. P. Adams of Princeton University a year ago prompted the Board to authorize the appointment of a special committee on Technical Lectures last fall, through which arrangements were made with Dr. M. I. Pupin, Professor of Electromechanics in Columbia University, New York, to deliver two lectures on the subject of the relation of the electromagnetic theory to the science of electrical engineering of the present day. The lectures were given in New York on April 29 and May 6, 1914. Dr. Pupin's lectures were planned to bring out the points of contact between Maxwell's electromagnetic theory and the ordinary and less broad electromagnetic theory which serves as the foundation of electrical engineering today.

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**International Electrical Congress.**—The Executive Committee of the Committee on Organization of the International Electrical Congress, San Francisco, 1915, which is invested with powers to carry on the work for the general committee, was reorganized during the year with a chairman, a vice-chairman, and nine other members, in order that it could more effectively carry on its work, which has developed considerably during the year. The question of financing the Congress was referred to the Board of Directors for consideration by the committee last fall, and it became necessary to make some adequate provision for funds to be available for this purpose until such time as the committee's income through subscriptions would enable it to finance the Congress independently of the Institute. This was accomplished by the passage of a resolution by which the Institute agreed to underwrite the expenses of the Congress to the extent of $15,000, with the understanding that the Institute is to be reimbursed to the full amount advanced if the Congress proves to be self-supporting, as expected, and is to receive the profits, if any. In agreeing to underwrite the expenses of the Congress, the Board took the view that inasmuch as the project of holding the Congress originated with the Institute, and as, by authority of the International Electrotechnical Commission, the Congress is being conducted under the auspices of the Institute, the responsibility for obligations incurred in connection with it rests upon the Institute. Additional information regarding the Congress may be found in the abstract of the report of the Executive Committee in the following pages.

**International Engineering Congress.**—This congress is entirely distinct from the Electrical Congress, and is to be held a week after the latter. It is being organized under the auspices of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the Society of Naval Architects and Marine Engineers, and the American Institute of Electrical Engineers. The Institute's interest in this congress is limited, on account of its obligations to the Electrical Congress, for which it is solely responsible, and upon the success of which its efforts must necessarily be largely centered. The Institute is, however, heartily in sympathy with the proposed engineering congress, is represented upon its Board of Management, and is actively cooperating in the work of preparation.

**Standardization Rules.**—One of the most useful and important activities which the Institute has undertaken in recent years, and upon which a very large amount of time and energy has been concentrated during the past year, is the preparation of a revised edition of the Standardization Rules. Credit for this work is due to the Standards Committee, which, after nearly two years of unremitting labor, has practically completed the revision of the rules, and it is expected that the revised rules will be referred to the Board of Directors for formal action at the coming Annual Convention.

**Foreign Relations.**—The Institute's relations with foreign engineering societies have continued harmonious and cordial. The reciprocal arrangement for the exchange of visiting member privileges with some of the foreign societies still remains in force, and has been availed of to a

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considerable extent. The Secretary has issued during the past year a large number of visiting member certificates to Institute members who have gone abroad, and an approximately equal number of certificates from foreign societies has been honored by the Institute.

An important step towards international representation was taken by President Mailloux last August by the appointment, upon authorization of the Board, of representatives of the Institute upon the United States National Committee of the International Illumination Commission, a newly-organized body formed from the International Photometric Commission at a meeting of the latter held for that purpose in Berlin, in August, 1913. In all, ten countries were represented by delegates. President Mailloux unofficially represented the Institute and took a conspicuous part in the proceedings. All of the statutes, resolutions and official documents of the Commission are to be drawn up in the French language, while the national committees may draw up translations which may be published on their own respective responsibilities. Several other American organizations are represented on the U. S. National Committee.

The very friendly relations which have always existed between the American Institute of Electrical Engineers and the Institution of Electrical Engineers of Great Britain have become more cordial than ever during the last year, through the personal efforts of their presidents, prior to and since their meeting at Berlin in August, 1913, as members of the official delegations from their respective countries to the meetings of the International Illumination Commission and of the International Electrotechnical Commission.

In accordance with arrangements previously made by letter and by cable a special conference of prominent members of the A. I. E. E. and the I. E. E. took place at London, in August, 1913, prior to the Berlin meetings. The purpose of this conference was to exchange and compare views, adjust and reconcile policies and programmes, and, in general, to secure coöperative, concerted action between the two countries in regard to electrical standardization and various cognate matters, and on questions of mutual interest to both. This conference was most effective in promoting good feeling, and in stimulating the desire for coöperation between the two bodies. It paved the way for an "*entente cordiale*" which, a few days later, at Berlin, produced telling results, by making the representatives from England and the United States work together in most satisfactory and effective manner, their joint efforts and influence having proved quite preponderating both in the organization of the I. I. C. and in the meetings of the I. E. C.

The desire for continued and systematic coöperation between the A. I. E. E. and the I. E. E. having already found expression at London and at Berlin, and the advantages thereof having become manifest since then, the matter was studied further on both sides and arrangements satisfactory to both sides were agreed upon. Formal action in carrying out these arrangements was taken by President Mailloux last February, when he obtained the authority of the Board to suggest to the Institution of Electrical Engineers that a Joint Conference Committee composed of representatives of the Institution and the Institute be organized to deal

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with matters regarding which concerted action between the standards committees of the two bodies might be desirable, and, if the suggestion was received favorably, to appoint the Institute's representatives. The Institution promptly accepted the invitation of the Institute to participate in the formation of such a joint committee.

**Committees and Departments.**—Upon entering into his administration of the Institute's affairs in August, 1913, President Mailloux, with the sanction of the Board, reorganized the technical committees and divided the work of the Institute into six departments, with a vice-president and manager at the head of each department as Councillor and Vice-Councillor. The features of the plan were fully described in the September, 1913, PROCEEDINGS.

The Standards Committee was considerably enlarged so as to permit the appointment of sub-committees of a suitable number.

Three new committees were appointed; namely, Electric Power, Electrically Propelled Vehicles, and Prime Movers. The Electric Power Committee was organized to cover a very broad field, and was divided into sub-committees on Power Stations, Power Generation, Protective Apparatus, Transmission, Distribution, Economics, and Engineering Data, each sub-committee having its own chairman and membership.

**Committee Reports.**—The following abstracts of the reports submitted by the chairmen of various permanent Institute committees give an outline of the activities of these committees. Much important work has also been accomplished by temporary committees appointed during the year for specific purposes; also by delegates of the Institute to meetings of other technical organizations and by representatives upon various boards, commissions, and other local and national bodies.

**Sections Committee.**—In accordance with the custom of previous years, the activities of the various Sections and Branches of the Institute are shown briefly in tabular form below:

| | Year Ending | | | | | | |
|---|---|---|---|---|---|---|---|
| | May 1 1908 | May 1 1909 | May 1 1910 | May 1 1911 | May 1 1912 | May 1 1913 | May 1 1914 |
| Sections | | | | | | | |
| Number of Sections | 21 | 24 | 25 | 25 | 28 | 29 | 30 |
| Number of Section meetings held.... | 141 | 169 | 187 | 208 | 231 | 244 | 233 |
| Total attendance... | 7476 | 16,427 | 16,694 | 15,243 | 19,800 | 22,825 | 22,626 |
| Branches | | | | | | | |
| Number of Branches | 22 | 26 | 31 | 36 | 42 | 47 | 47 |
| Number of Branch meetings held..... | 143 | 198 | 237 | 255 | 281 | 357 | 306 |
| Attendance..... | 4128 | 8,443 | 10,255 | 10,714 | 10,255 | 11,808 | 11,617 |

One new Section has been formed within the last year, at Panama. Judging from the notices that have come from the new Section, it has had a highly successful inauguration.

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The Pacific Coast membership have not as yet held their annual convention, but it is held over until September, thereby making it the first of the Institute meetings which will occur in the next administrative year. This will be the sixth of these Pacific Coast conventions which have been held among the six Pacific Coast Sections. The convention this year will be held in Spokane, Wash., September 9, 10 and 11.

These conventions have been highly influential in maintaining the solidarity of the Institute membership on the Pacific Coast.

The Sections and Branches continue to maintain the important place in Institute activities that they have maintained since their inauguration twelve years ago.

**Meetings and Papers Committee.**—The Meetings and Papers Committee has had general supervision of the arrangements for the Institute meetings and conventions held throughout the country during the year. In providing the program for these meetings the committee has had the coöperation and assistance of various other Institute committees. The chairman of the committee contributing the paper for discussion at a meeting has usually presided at the technical session at that meeting.

The committee is now making preparation for the Annual Convention. which is to be held in Detroit, Mich., June 23-26, 1914. The committee is pursuing the same policy as last year in limiting the number of papers to be presented, having found this a great advantage, as it affords a longer time for discussion and eliminates the necessity for parallel sessions.

**New York Reception Committee.**—The New York Reception Committee has arranged for the smokers which have been held at Institute headquarters in connection with the monthly meetings. These smokers have been supported entirely by voluntary contributions from members residing in and near New York.

**Standards Committee.**—The membership of the Standards Committee, as appointed last year, has been larger than heretofore, so as to permit of the division of the committee into sub-committees on specific subjects. Six sub-committees have been created, to deal with the subjects of Rating, Telegraph and Telephone Standards, Railroad Standards, Nomenclature and Symbols, Cables, and Rating and Testing of Control Apparatus. Each sub-committee has been presided over by a chairman.

The committee, as a whole, has bent its energies during the year to producing a new edition of the Standardization Rules. Since the last edition was issued in 1911 many rules in it have ceased to be useful, and should be superseded. A large amount of material for the new edition was laid before the Institute in the papers read at the New York Midwinter Convention of February, 1913. Since that date the Standards Committee has been actively engaged in drawing up the proposed new rules and in circulating the proposals for discussion. Preliminary drafts of sections of the proposed new rules were printed in December, 1913, January, February, March and April, 1914. Many of these drafts have been extensively circulated, especially those prepared by the sub-committee on Rating. The sub-committees have successively discussed and modified these drafts in local meetings attended by specialists from different parts of the country.

The meeting of the whole committee in April, at the Institute rooms.

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lasted two full days. The latest revision is now being prepared for further distribution, and for final discussion at a meeting in June. It is expected that the committee will then be able to submit the new edition to the Board of Directors at the Annual Convention.

**Code Committee.**—The Code Committee was represented by its chairman at a Conference on Fire Prevention held in Philadelphia in October, 1913, under the auspices of the Philadelphia Fire Prevention Commission. The outcome of the conference was that the work which it was expected would be handled by the Commission is to be taken care of by the Public Policy Committee of the National Board of Fire Underwriters.

The chairman of the committee also represented the Institute at the biennial meeting of the Electrical Committee of the National Board of Fire Underwriters held in Boston in April. At this meeting the committee appointed to reconstruct Rule 13, dealing with outside construction, decided to postpone definite action until the result of the work of the joint committee of the American Railway Association on the joint use of poles is known.

**Library Committee.**—A great deal of time and study has been given to the Library during the year, by the Library Board composed of representatives of the founder societies, with a view to increasing its efficiency. The members of the Library Committee represent the Institute upon this Board. The complete report of the committee will be published in an early issue of the PROCEEDINGS.

**Railway Committee.**—The Railway Committee has endeavored to make progress in getting comparisons of actual equipment and operating costs characteristic of the various direct-current and single-phase electrical installations connected with trunk line traffic, but thus far has been unsuccessful, because, while some of the officials concerned have been willing to make the necessary exhibits, they have found themselves unable to do so without the coöperation of all concerned. Efforts to this end have therefore been deferred for the present.

**Electric Illumination Committee.**—This committee was not appointed until November last, by which time the Institute's work for the administrative year was well under way. The committee has held one meeting and has had considerable correspondence, including negotiations with the Illuminating Engineering Society with regard to joint work and obtaining papers on the subject of illumination for the Annual Convention and later meetings of the Institute.

**Electric Power Committee.**—The Electric Power Committee has been principally engaged with the formation of its plans for the development and holding of the Midwinter Convention. It is anticipated that during the remainder of the year an outline will be prepared of the standardization work which can be desirably handled by the committee and of the specifications which may be outlined by it. Preparations are also being made to take care of one session of the Annual Convention in Detroit.

The activities of the sub-committees on Power Stations, Power Generation, Transmission, Distribution, Economics and Engineering Data are covered in the following abstracts.

**Power Stations Sub-Committee.**—The Power Stations Committee held many meetings in Boston, which were generally limited to those members

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residing in Boston and its vicinity, and it also had considerable correspondence with distant members, with the object in view of outlining the duties of the committee and carrying them out efficiently. The committee took the responsibility for one of the sessions of the Midwinter Convention in New York in February, and provided papers for that session.

**Power Generation Sub-Committee.**—Under the auspices of this committee there was presented at the Midwinter Convention in New York a paper by Dr. Cary T. Hutchinson, on *The Economical Capacity of a Combined Hydroelectric and Steam Plant.*

**Transmission Sub-Committee.**—The Transmission Committee provided the papers for one of the sessions at the Midwinter Convention in New York in February. The principal paper consisted of a general report comprising data and records of experience contributed by the various members of the committee. Appended to the report were four short articles all relating to the general subject of transmission.

**Distribution Sub-Committee.**—The Distribution Committee prepared a report with nine appendixes, each covering a specific branch of electrical distribution. The report proper referred to some of the newer and larger general problems and the tendencies in generalized distribution. The report and appendixes, covering practically the entire field of electrical distribution, were presented and discussed at the Midwinter Convention.

**Economics Sub-Committee.**—The Economics Committee has concentrated its energies upon an effort to arrive at a proper method for recording power costs. The object to be attained is to record these costs so that the results will permit a true comparison of stations operating under different circumstances.

**Engineering Data Sub-Committee.**—The Engineering Data Committee, in cooperation with the Handbook Committee and the Electric Power Committee, provided the program for one session at the recent Midwinter Convention. The committee has in hand, and now has revised and ready for approval, the model or skeleton high-tension insulator testing specification which was prepared last year by the High-Tension Transmission Committee. It is believed that this specification will be found of considerable value in an educational way and in the establishment of uniformity in practise in insulator tests. The committee has also been continuing the collection of data on high-tension plants which was initiated last year, and now has in hand reports from some 20 companies, most of them containing valuable material. These are being analyzed and it is expected that the analysis will be completed for the Annual Convention. The committee is also trying out the plan of sending circular letters to a selected list of engineers asking for their experience or practise in regard to some particular question of engineering interest, usually at the request of some member wishing information on that particular topic. Such pertinent replies as are received are embodied in a circular letter and sent to the appropriate list of members.

**Industrial Power Committee.**—This committee was not appointed until late in October, at which time the schedule of regular meetings for the year had been practically decided upon. Consequently, the committee has concentrated its efforts towards arranging for papers to be

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presented at the Industrial Power session at the Annual Convention in Detroit in June. It is hoped that these plans will result in a satisfactory meeting. The committee expects to arrange an exhibit of moving pictures of the iron and steel industry for the Annual Convention.

**Telegraphy and Telephony Committee.**—The Telegraphy and Telephony Committee held no meetings during the year, owing to the wide geographical distribution of its membership. Under arrangements with the Meetings and Papers Committee it accepted the responsibility for the program of the Institute meeting held in New York on March 13, 1914. The Institute of Radio Engineers was invited to participate in this meeting. Three papers were presented; one dealing with railway telephone and telegraph practise, another with a study of telephone traffic in automatic systems, and the third with long-distance radio transmission.

The chairman had considerable correspondence with the members of the committee in regard to the collection and compilation of engineering data in the allied fields of telegraphy and telephony. A number of proposals were advanced by certain members of the committee, and these were submitted to the whole committee for discussion, but no decisive action resulted.

**Electrochemical Committee.**—The work of the Electrochemical Committee for the past year has been largely devoted to attempts to obtain suitable papers on electrochemistry treated from an engineering viewpoint. Owing to the scattered geographical distribution of its members it has been necessary to carry on the work through correspondence. Three papers were promised during the year, of which one will be presented at the Annual Convention. The remaining two papers are nearly completed and are definitely promised for next season and may be available in the fall.

The committee has also considered the question of collecting technical data in the electrochemical field with a view to collating this for publication under the auspices of the Institute, in line with similar work which is being carried on by several of the other technical committees. Many difficulties have been found in the way of this work, however, and no actual data were collected during the year. One feature that appears in the way of collecting engineering data relating to electrochemistry is the fact that some of the electrochemical industries have not been standardized to a sufficient extent to justify the standardization of the engineering data relating to these industries. Further, such data as the ordinary chemical and electrochemical constants would seem to be more properly collected in handbooks and textbooks, while new data of this kind would seem to be more properly collected by the Electrochemical Society. This society has a committee on electrochemical standards and units.

**Electrophysics Committee.**—The work of the Electrophysics Committee has been directed (1) to the securing of papers on subjects relating to the physical theory underlying electrical engineering, (2) to the stimulation of interest in experimental research, and (3) to the arrangement of a joint meeting of the Institute and the American Physical Society.

Up to the present time 10 papers have been considered. Five of these were presented at the Washington meeting, April 24 and 25, two are under consideration for the Annual Convention, and two have been rejected as unsuitable. Promises have also been received of two additional papers

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Through correspondence the committee has continued its efforts to secure a list of promising subjects for research. So far the results of this attempt have not been numerous, but it is hoped that by continued effort in this direction valuable material may eventually be collected.

The committee arranged the Institute meeting held in Washington April 24 and 25 in coöperation with the American Physical Society. The coöperation of the National Bureau of Standards and the Baltimore and Washington Sections was also secured. Arrangements were made for an interesting exhibit of measuring instruments and other apparatus relating to electrical engineering.

**Committee on Use of Electricity in Mines.**—During the past year the committee has given considerable attention to the question of regulations for electrical installations in mines. After a study had been made of the situation it was decided that it would be desirable to obtain a discussion of mining regulations from individuals interested in this work. There is no recognized standard for electrical work in mines, and on account of the increasing importance of this work it was considered that some standardization is desirable. A two-day meeting of the Institute was held in Pittsburgh on April 9 and 10, at which various European and American mining codes were discussed. In addition a number of papers were read which produced an interesting exchange of ideas. It was suggested that the subject of electrical installation in mines should receive attention from the committee for 1914-1915, with the object of obtaining joint action with other national societies toward the formation of a set of rules meeting with the approval of mining and electrical engineers, which could be used as a basis for standardization and future legislation by state governments.

**Committee on Use of Electricity in Marine Work.**—This committee has provided the two papers which will be presented at the New York meeting on May 19. These are, *Electricity the Future Power for Steering Vessels*, and *The Future of Electric Heating and Cooking in Marine Service*. The committee has held two meetings during the year and steps have been taken toward the formulation of rules covering electrical installations on shipboard, and the collection of data showing present good practise in marine installations.

**Committee on Electrically Propelled Vehicles.**—In view of the rapid growth in the use of electric vehicles for both pleasure and commercial purposes it appeared advisable to have an Institute Committee on Electrically Propelled Vehicles. The committee has held only one formal meeting, but the chairman has been in communication with the various members of the committee throughout the year. The general opinion of the members of the present committee is that the committee should confine its attention to the engineering features involved in the design and use of electric vehicles, and that questions of standardization of equipment and parts should be referred to the Standardization Committee of the Electric Vehicle Association of America.

At the request of the chairman of the Standardization Committee of the Electric Vehicle Association of America, the Committee on Electrically Propelled Vehicles has requested the Standards Committee of the Institute to approve the standard charging plug adopted by the Associa-

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tion, and has also requested the Standards Committee to endeavor to secure the adoption of this plug by the U. S. National Committee of the International Electrochemical Commission.

**Committee on Records and Appraisals of Property.**—This committee has decided that its efforts this year should be directed chiefly to formulating, as far as possible, a statement of the general principles which should underlie the production of correct appraisals and records of properties, and that it would be better not to attempt to lay more than a basic foundation upon which next year's committee can work.

**Prime Movers Committee.**—The Prime Movers Committee is now engaged on a report which it is hoped will be presented at the Annual Convention, covering the present status of the art of prime movers. This report will not only cover the relative efficiencies, but also the economics of the situation.

**Educational Committee.**—The Educational Committee planned to prepare a report dealing particularly with the development of more effective means of utilizing existing institutions for vocational training. The committee has been in correspondence with the secretaries of the Sections of the Institute, and individual members of the committee have under way special studies, all bearing on the same general subject. The report is nearing completion, but it will not be possible to present it at the Annual Convention as it was hoped could be done, and therefore it is now planned to refer it to next year's committee.

**Committee on Technical Lectures.**—In accordance with suggestions received at the time of its appointment, the Committee on Technical Lectures arranged for two lectures on the subject of " The Electromagnetic Theory and Its Relation to the Science of Electrical Engineering of the Present Time," by Dr. M. I. Pupin, Professor of Electromechanics at Columbia University. These lectures were given in New York on April 29 and May 6, and were largely attended by Institute members and others.

The committee has considered the subject of arranging for representatives of the Institute to deliver popular lectures on engineering subjects in coöperation with the boards of education of various cities. It is the sentiment of the committee that it is desirable that this work should be undertaken next year.

**Editing Committee.**—Twelve numbers of the PROCEEDINGS have been published under the auspices of the Editing Committee since April 30th, 1913; the total number of pages being practically the same as for the past two years. During the past year the committee adopted the policy of cutting down the discussions before sending the stenographer's reports to the various speakers for revision. By this means the length of discussion is indicated by the Editing Committee in advance, and considerable correspondence in regard to condensation of discussion has thereby been eliminated. This practise has apparently proved equally satisfactory to the authors and the Editing Committee. During the past year the separate pages for the titles and abstracts of papers in the PROCEEDINGS have been eliminated and the abstract included on the title page as part of the paper. The typographical style of the PROCEEDINGS has thereby been improved and a saving of over $1,000 effected by the elimination of two pages for each of the papers published. The change

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in the weight and character of the paper on which the 1912 issue of the TRANSACTIONS was printed permitted this volume to be issued in two parts instead of three as in the previous year, thereby effecting considerable saving in shelf space for the volume as well as a substantial saving in cost of publication.

**Indexing Transactions Committee.**—The Index to the TRANSACTIONS covering the period from 1884 to 1910 was completed last fall. Volume II, covering the years 1901 to 1910, was issued in September, and Volume I, covering the years 1884 to 1900, was issued a few months later. Announcements that the volumes were ready and would be sent gratis to any Institute member desiring them, were published in the September and December 1913 issues of the PROCEEDINGS, together with full information regarding the index, and the volumes have since had a wide distribution.

The index consists of two separate parts, each intended for a distinct purpose.

1. An index of papers in which they are classified in natural groups and arranged chronologically in each group. In each case the title and author are given, with a brief synopsis of the contents of the paper, and the names of those who took part in the discussion. Reference is given to volume number, year and page.

2. A topical index of specific data and information arranged alphabetically. This part of the index furnishes a guide to all the information contained in the TRANSACTIONS, and is grouped naturally under nouns and phrases, followed by modifying adjectives and sub-classes, all arranged alphabetically.

An index arranged on a similar plan, covering the matter contained in the papers and discussions during the year, is now published in each annual volume of the TRANSACTIONS, beginning with 1911.

**Public Policy Committee.**—The Public Policy Committee has held three meetings to consider and report upon matters referred to it by the President and Board of Directors; namely, the matter of sending a memorial to the President of the United States urging the appointment of one or more engineers on the Interstate Commerce Commission; to consider the continuation of the Institute's representation on the Advisory Board of the National Conservation Congress; and, to consider the invitation from the Secretary of the Interior, to confer with him on the subject of proposed legislation to govern the issue of permits for hydroelectric development on the public domain.

**Patent Committee.**—At the request of the Patent Committee a meeting of the Public Policy Committee was called in April to consider certain information which had been brought to the attention of the chairman of the Patent Committee in regard to the U. S. Patent Office. As a result of the meeting the Public Policy Committee recommended the appointment of a special committee of the Institute to appear before the House Committee on Appropriations, in Washington, and urge the inclusion in the Sundry Civil Bill of the sum requested by the Hon. Thomas Ewing, Commissioner of Patents, for the preparation of plans for a new Patent Office.

**Committee on Relations of Consulting Engineers.**—This committee has kept in touch with the practise and experience of the American In-

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stitute of Consulting Engineers in the use of the schedule of recommended charges adopted by that Institute, and has collected valuable data relating to the regulations governing the fees of architects and consulting engineers as adopted in certain foreign countries.

**Committee on Code of Principles of Professional Conduct.**—This committee has had nothing referred to it for action during the year. The code as adopted two years ago has been used as a basis by other societies and organizations for the formulation of codes of ethics or principles of professional conduct for themselves.

**Constitutional Revision Committee.**—As reported to the Board last January, the general sentiment of the Constitutional Revision Committee was that the best interests of the Institute would be served by not initiating any amendments to the Constitution this year. There are a number of minor points in the Constitution which could be made clearer or more consistent. Such changes might best be brought to the attention of the membership for vote when important constitutional changes are also to be voted upon.

It is thought by the committee that the present Constitution goes too much into detail with reference to certain matters, particularly concerning committees. The duties of certain committees, presumably the Executive Committee, the Board of Examiners, the Tellers, Finance, Sections, Editing, and Meetings and Papers Committees, should be dealt with in the Constitution. The other committees might be more properly regulated by the by-laws.

**U.S. National Committee, International Electrotechnical Commission.**—The Commission held a meeting in Berlin in September, 1913. The U. S. National Committee was represented at this meeting by President Mailloux and Messrs. Bell, Hobart, Kennelly, and Sharp. An advance report of the meeting was prepared by the Secretary of the American delegation and printed in the Institute PROCEEDINGS for November 1913, pp. 2148-2162.

Since the date of the last committee report in May 1913 the following publications have been issued by the Central Office:

| | |
|---|---|
| June 1913, No. 23 | List of Members |
| June 1913, No. 24 | Fourth Annual Report to December 1912 |
| Nov. 1913, No. 25 | Résumé of Meetings of Special Committees held in Berlin, September 1913. |
| Dec. 1913, No. 26 | Résumé of Meetings of Special Committees held in Berlin, September 1913. |
| Jan. 1914, No. 27 | International Symbols Adopted at Berlin, September 1913. |
| Mar. 1914, No. 28 | International Standard of Resistance for Copper. |

Several meetings of the committee have been held during the year and communication has been maintained with the other national committees, on various topics, through the Central Office in London.

In many ways the I. E. C. has accomplished and is accomplishing results of widespread benefit. The U. S. National Committee continues to take a prominent and active part in this work as it has in the past.

**Committee on Organization of International Electrical Congress.**—During the year ending April 30, 1914, the work of organizing the Inter-

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national Electrical Congress has taken definite form. Early in the year the Executive Committee of the Committee on Organization was reorganized with a chairman, a vice-chairman and seven members, most of whom are chairmen of sub-committees charged with the responsibility of the proper conduct of certain phases of congress work. An Honorary President and Honorary Secretary of the Congress were also appointed, both of whom are *ex officio* members of the Executive Committee.

President Mailloux also appointed as Honorary Members of the Committee on Organization prominent engineers in foreign countries, bringing the total membership of the committee up to about 335 members.

The Executive Committee has been invested with plenary powers to conduct the organization work on behalf of the committee at large.

A number of important steps were taken by the Executive Committee during the year toward promoting the successful organization of the Congress. Membership fees were fixed at the lowest practicable point, with the object in view of securing the widest possible dissemination of the Congress transactions and the largest practicable membership.

Invitations to subscribe to membership in the Congress were issued beginning about March 1, 1914. These were sent first to Institute members, and are now being issued in European countries. Invitations to present papers before the Congress have been issued to a carefully selected list of approximately 150 engineers in countries other than the United States. Similar invitations will shortly be issued to American engineers. Steps are being taken to secure official governmental representation in the Congress.

The committee reports an encouraging display of interest in the Congress, and the conditions appear propitious for a highly successful and very useful Congress.

**Edison Medal.**—By the unanimous vote of all of the members of the Edison Medal Committee, the fifth Edison Medal was awarded on December 10, 1913, to Mr. Charles F. Brush, of Cleveland, Ohio, "for meritorious achievement in the invention and development of the series arc lighting system." The presentation will be made during the Annual Convention at Detroit.

**Board of Examiners.**—The Board of Examiners has held 11 meetings during the year. It has examined and referred to the Board of Directors with its recommendations a total of 1373 applications of all classes. A summary of these is as follows:

| | | |
|---|---|---|
| Recommended for election to the grade of Associate | 685 | |
| Recommended for election to the grade of Member | 45 | |
| Recommended for election to the grade of Fellow | 3 | |
| Not recommended for election to the grade of Associate | 1 | |
| Not recommended for election to the grade of Member | 9 | |
| Recommended for enrolment as students | 519 | 1,262 |
| Recommended for transfer to the grade of Member | 46 | |
| Not recommended for transfer to the grade of Member | 20 | |
| Recommended for transfer to the grade of Fellow | 34 | |
| Not recommended for transfer to the grade of Fellow | 11 | 111 |
| Total number of applications considered | | 1,373 |

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**Membership.**—The Membership Committee deemed it inadvisable to attempt a membership campaign by direct circulation of literature soliciting new members. It was felt that this work could be carried on to better advantage through the Sections, and accordingly, a circular letter was issued inviting their coöperation. Many of the Sections have active membership committees and all of them are coöperating in advancing the interest of the Institute by obtaining desirable new members. The following table shows the number of members in each grade, the total membership, and the additions and deductions which have been made during the year.

| | Honorary Member | Fellow | Member | Associate | Total |
|---|---|---|---|---|---|
| **Membership, April 30, 1913.** | **5** | **316** | **847** | **6486** | **7654** |
| Additions: | | | | | |
| Elected | 1 | 4 | 42 | 700 | |
| Transferred | | 121 | 264 | | |
| Reinstated | | | 6 | 44 | |
| Deductions: | | | | | |
| Died | 1 | 1 | 7 | 28 | |
| Resigned | | 1 | 6 | 138 | |
| Dropped | | | 9 | 384 | |
| Transferred | | | 110 | 275 | |
| Membership, April 30, 1914. | 5 | 439 | 1027 | 6405 | 7876 |

Net increase in membership during the year..... 222

*Deaths.*—The following deaths have occurred during the year:

Honorary Member.—Sir William H. Preece.

Fellow.—Stephen D. Field.

Members.—Julius C. Calisch, Richard N. Dyer, Edwin J. Houston, Francis W. Jones, F. V. T. Lee, W. D. Marks, W. A. Pearson.

Associates.—L. E. Beilstein, R. E. Bowser, E. A. Byrnes, J. R. Calhoon, M. M. Corbin, C. E. Delafield, R. M. Ferris, E. M. Filine, H. H. Fulton, L. J. Gallagher, P. F. Harbolt, L. D. Hitzeroth, R. M. Hopkins, George R. Kempton, J. A. Kraeuchi, A. W. Lindgren, L. N. Peart, William Pitt, David H. Roberts, A. G. Rodgers, Eugene Romig, Clinton B. Smith, Wilson B. Strong, H. H. Struthers, C. Edgar Titzel, George Westinghouse, C. W. Whitman, Sidney Woodfield.

Total deaths, 37.

**Finance Committee.**—The following correspondence and financial statements form a complete summary of the work of the Finance Committee for the year.

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NEW YORK, May 12, 1914.

BOARD OF DIRECTORS,

*American Institute of Electrical Engineers.*

*Gentlemen:*

Your Finance Committee respectfully submits the following report for the year ending April 30, 1914.

During the past year the committee has held monthly meetings, has passed upon the expenditures of the Institute for various purposes, and otherwise performed the duties prescribed for it in the Constitution and By-laws. Haskins and Sells, chartered accountants, have audited the Institute books, and their certification of the Institute finances follows.

In company with your Secretary and a member of the firm of chartered accountants, the committee has examined the securities held by the Institute and finds them to be as stated in the accountants' report.

Early in 1913, in consequence of certain extraordinary expenses incurred during the previous year, the Board was obliged to negotiate a loan of $10,000 in order to meet the Institute's current obligations. The note was taken up several months later, when funds began to accumulate through the payment of dues, but it appeared inevitable at the time that a similar condition must arise early in the present year. Such, however, has not been the case; the income from dues has been sufficient to meet all expenditures and to take up the note referred to, without in any way curtailing the Institute's activity. In fact, its field has broadened considerably during the year.

It will be noted that there is a surplus of $14,966.39 for the fiscal year. Of this amount, $3,805.94 is made up of accessions to the Library—volumes and fixtures and to works of art.

A change has been made in the form of the report, which will be particularly noted in Exhibit (b), the report for the past fiscal year stating the revenue and the expenses for the year, in place of receipts and disbursements. This change we believe will show more clearly the financial operations than the form previously employed.

It will also be noted that the financial affairs of the Institute are in excellent condition, and there is every reason to anticipate that the coming year will prove equally prosperous, which should enable the Institute to take care of the amount it has underwritten in connection with the International Electrical and International Engineering Congresses, to be held in 1915, without impairment of its invested surplus.

Respectfully submitted,

J. FRANKLIN STEVENS,
*Chairman Finance Committee*

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NEW YORK, May 11, 1914.

American Institute of Electrical Engineers,
33 West 39th Street, New York.

Dear Sirs:

Pursuant to engagement, we have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1914, and submit herewith our certificate and the following described exhibits:

EXHIBIT

" A "—General Balance Sheet—April 30, 1914.

" B "—Statement of Income and Profit & Loss for the Year Ended April 30, 1914.

Yours truly,
(Signed) HASKINS & SELLS
Certified Public Accountants.

## CERTIFICATE

We have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1914, and

WE HEREBY CERTIFY that the accompanying General Balance Sheet properly sets forth the financial condition of the Institute on April 30, 1914, that the Statement of Income and Profit & Loss for the year ended on that date is correct, and that the books of the Institute are in agreement therewith.

(Signed) HASKINS & SELLS
Certified Public Accountants.

NEW YORK,
May 11, 1914.

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## AMERICAN INSTITUTE OF

### GENERAL BALANCE SHEET

EXHIBIT A.

ASSETS.

| | | | |
|---|---|---|---|
| LAND AND BUILDING: | | | |
| Interest in United Engineering Society's Real Estate, No. 25 to 33 West 39th Street: | | | |
| Building | | $353,346.61 | |
| One-third Cost of Land | | 180,000.00 | |
| Total Land and Building | | | $533,346.61 |
| EQUIPMENT: | | | |
| Library—Volumes and Fixtures | | $38,387.30 | |
| Works of Art, Paintings, etc. | | 3,001.35 | |
| Office Furniture and Fixtures | | 10,786.11 | |
| Total Equipment | | | 52,174.76 |
| INVESTMENTS: | | | |
| Bonds: | | | |
| New York City, 4½%, 1917, Par $8,000.00 | | $8,362.50 | |
| New York City, 4½%, 1957, Par $22,000.00 | | 23,590.00 | |
| City of Wilmington, Delaware, 4½%, 1934, Par $15,000.00 | | 15,997.50 | |
| Chicago, Burlington & Quincy Railroad Company, 4%, 1958, Par $15,000.00 | | 14,606.25 | |
| Total Investments | | | 62,556.25 |
| WORKING ASSETS: | | | |
| Publications entitled "Transactions," etc. | | $8,674.25 | |
| Badges | | 911.15 | |
| Total Working Assets | | | 9,585.4 |
| CURRENT ASSETS: | | | |
| Cash | | $3,410.26 | |
| Accounts Receivable: | | | |
| Members for entrance fees and past dues | | 9,640.50 | |
| Advertisers | | 1,564.75 | |
| Miscellaneous | | 999.15 | |
| Interest Accrued—Investments | | 831.25 | |
| Interest Accrued—Bank Balances | | 77.17 | |
| Total Current Assets | | | 16,523.08 |
| FUNDS: | | | |
| Land, Building, and Endowment Fund: | | | |
| Cash | $7,513.54 | | |
| Interest Accrued | 78.20 | | |
| | | $7,591.74 | |
| Life Membership Fund: | | | |
| Cash | $5,431.91 | | |
| Interest Accrued | 69.00 | | |
| | | 5,500.91 | |
| International Electrical Congress of St. Louis—Library Fund: | | | |
| Cash | $566.24 | | |
| New York City Bonds, 4½%, 1957, Par $2,000.00 | 2,268.00 | | |
| Interest Accrued | 45.00 | | |
| | | 2,879.24 | |
| MAILLOUX FUND: | | | |
| Cash | 95.80 | | |
| New York Telephone Company Bond, 4½%, 1939 | 1,000.00 | | |
| Interest Accrued | 22.50 | | |
| | | 1,118.30 | |
| Total Funds | | | 17,090.19 |
| Total | | | $691,276.29 |

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## ELECTRICAL ENGINEERS

### APRIL 30, 1914

| | | |
|---|---|---|
| LIABILITIES. | | |
| Bond and Mortgage—United Engineering Society—One-third Interest in Land, 25 to 33 West 39th Street | | $54,000.00 |
| CURRENT LIABILITIES: | | |
| Accounts Payable—Subject to Approval by the Finance Committee | 5,561.78 | |
| Interest Accrued on Bond and Mortgage | 720.00 | |
| Members' dues paid in advance | 814.75 | |
| Entrance fees and dues advanced by applicants for membership | 72.00 | |
| Total Current Liabilities | | 7,168.53 |
| RESERVES: | | |
| Land, Building and Endowment Fund | $7,591.74 | |
| Life Membership Fund | 5,500.91 | |
| Mailloux Fund | 1,118.30 | |
| International Electrical Congress of St. Louis—Library Fund | 2,879.24 | |
| Total Funds | 17,090.19 | |
| Reserve for Depreciation of Furniture and Fixtures | 4,867.78 | |
| Total Reserves | | 21,957.97 |
| SURPLUS: Per Exhibit "B" | | 608,149.79 |
| Total | | $691,276.29 |

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## AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

### STATEMENT OF INCOME AND PROFIT AND LOSS

### FOR THE YEAR ENDED APRIL 30, 1914

**EXHIBIT B.**

| | | | |
|---|---|---|---|
| **REVENUE:** | | | |
| Entrance Fees | | $4,228.75 | |
| Dues | | 85,915.63 | |
| Students' Dues | | 4,245.00 | |
| Transfer Fees | | 670.00 | |
| Advertising | | 10,041.92 | |
| Subscriptions | | 3,061.70 | |
| Sales of "Transactions," etc. | | 2,408.12 | |
| Badges Sold | $2,104.00 | | |
| Less Cost | 1,644.81 | 459.19 | |
| Interest on Investments | | 2,626.00 | |
| Interest on Bank Balances | | 316.69 | |
| Exchange | | 24.94 | |
| Total | | | $113,997.94 |
| **EXPENSES:** | | | |
| Meetings and Papers Committee: | | | |
| Salaries | | $4,300.00 | |
| Binding and Mailing Proceedings | | 4,807.60 | |
| Printing Proceedings | | 8,504.86 | |
| Engraving Proceedings | | 1,022.57 | |
| Paper and Cover Paper | | 5,056.94 | |
| Envelopes | | 821.12 | |
| Stationery and Miscellaneous Printing | | 133.47 | |
| General Expense | | 148.71 | |
| Meetings | | 6,106.69 | |
| Volume No. 30 | | 3.60 | |
| Volume No. 31 | | 11,892.31 | |
| Total | | $42,797.87 | |
| Deduct Increase in Inventory of Publications: | | | |
| May 1, 1913 | $7,628.25 | | |
| April 30, 1914 | 8,674.25 | 1,046.00 | $41,751.87 |
| Executive Department: | | | |
| Salaries | | $14,842.00 | |
| General Expense | | 1,645.17 | |
| United Engineering Society—Assessments | | 3,375.00 | |
| Express | | 206.65 | |
| Postage | | 3,602.62 | |
| Advertising | | 2,010.95 | |
| Office Furniture and Fixtures | | 287.72 | |
| Stationery and Miscellaneous Printing | | 3,600.13 | |
| Year Book and Catalogue | | 2,687.49 | |
| Interest on Bond and Mortgage | | 2,160.00 | |
| Interest on Note Payable | | 18.75 | |
| Engraving | | 13.06 | 34,449.54 |
| Forward | | | $76,201.41 |
| REVENUE—(Forward) | | | $113,997.94 |

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| | | |
|---|---|---|
| REVENUE—(Forward) | | $113,997.94 |
| EXPENSES—(Forward) | | 76,201.41 |
| Sections Committee: | | |
| Section Meetings | $3,651.32 | |
| Branch Meetings | 224.58 | |
| Delegates Convention Expenses | 1,613.36 | |
| Salary and Traveling Expenses, Honorary Secretary | 4,353.78 | |
| Salaries, New York Office | 2,268.00 | |
| Stationery and Printing, New York Office | 674.22 | |
| Express on Advance Copies | 61.56 | 12,846.82 |
| General: | | |
| Library | $3,310.66 | |
| Indexing "Transactions," | 1,832.21 | |
| International Electrotechnical Commission | 275.54 | |
| Finance Committee | 150.00 | |
| Standards Committee | 612.60 | |
| President's Special Appropriation | 228.30 | |
| Annual Function | 365.00 | |
| Law Committee | 500.00 | |
| International Engineering Congress, 1915 | 875.00 | |
| International Illumination Committee | 100.00 | |
| Membership Committee | 4.25 | 8,253.56 |
| Add: | | |
| Increase in Accounts Payable—Subject to Approval by the Finance Committee, Undistributed at: | | |
| May 1, 1913 | $4,335.91 | |
| April 30, 1914 | 5,561.78 | 1,225.87 |
| Total Expenses | | $98,527.66 |
| NET REVENUE | | $15,470.28 |
| PROFIT & LOSS CREDITS: | | |
| Accessions: | | |
| Library Volumes and Fixtures | $3,460.94 | |
| Works of Art | 345.00 | |
| Total | | 3,805.94 |
| GROSS SURPLUS FOR THE YEAR | | $19,276.22 |
| PROFIT & LOSS CHARGES: | | |
| Uncollectible Dues Written Off | $3,180.00 | |
| Reservation for Depreciation of Furniture and Fixtures | 1,129.83 | |
| Total | | 4,309.83 |
| NET SURPLUS FOR THE YEAR | | $14,966.39 |
| SURPLUS, MAY 1, 1913 | | 593,183.40 |
| SURPLUS, APRIL 30, 1914 | | $608,149.79 |

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## AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

### STATEMENT OF CASH RECEIPTS AND DONATIONS FOR DESIGNATED PURPOSES. ALSO DISBURSEMENTS, FOR THE YEAR ENDED APLIL 30, 1914.

### EXHIBIT C.

| | |
|---|---|
| RECEIPTS AND DONATIONS: | |
| Land, Building and Endowment fund—Donations, Interest, etc | $398.22 |
| Life Membership Fund | 362.92 |
| International Electrical Congress of St. Louis Library Fund Donations, and Interest | 94.15 |
| Mailloux Fund, Interest | 45.00 |
| General Library Fund, Interest | 6.97 |
| Total | $907.26 |
| DISBURSEMENTS: | |
| Life Membership Fund | $456.88 |
| General Library Fund | 284.92 |
| Mailloux Fund | 26.75 |
| Weaver Fund | 6.69 |
| Total | 775.24 |

### RECEIPTS AND DISBURSEMENTS PER YEAR PER MEMBER.

During each fiscal year for the past eight years.

| Year ending April 30 | 1907 | 1908 | 1909 | 1910 | 1911 | 1912 | 1913 | 1914 |
|---|---|---|---|---|---|---|---|---|
| Membership, April 30, each year | 4521 | 5674 | 6400 | 6681 | 7117 | 7459 | 7654 | 7876 |
| Receipts per Member | $12.21 | $13.01 | $13.21 | $13.35 | $13.37 | $13.19 | $13.45 | $14.08 |
| Disbursements per Member | 11.62 | 11.73 | 10.49 | 12.03 | 11.03 | 12.44 | 15.57 | 12.86 |
| Credit Balance per Member | $ .59 | $1.28 | $2.72 | $1.32 | $2.34 | $ .75 | *$2.12 | $1.22 |

*Deficit.

Respectfully submitted for the Board of Directors,

F. L. HUTCHINSON, *Secretary.*

New York, May 19, 1914.

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Engineering Library

# PROCEEDINGS

*OF THE*

# American Institute

*OF*

# Electrical Engineers

*Volume XXXIII*
*Number 6*

**JUNE, 1914**

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*Per Year, $10.00*

JUN 12 1914

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**Eck, Justus.** Light, Radiation and Illumination. Translated from the German of Paul Hogner. 59 illustrations, folding plates. 5½x8¾. Cloth. 100pp. 1913. Net $2.50

**Johnson, J. H.** Arc Lamps and Accessory Apparatus. (Electrical Installation Manual Series.) Illustrated. 4½x6¼. Cloth. 135pp. 1911. Net $0.75

**Nerz, F.** Searchlights: Their Theory, Construction and Application. Translated by Charles Rogers. 47 illustrations. 6x9 Cloth. 145pp. New York. 1907. Net $3.00

**Palaz A.** Treatise on Industrial Photometry, specially applied to electric lighting. Translated from the French by G. W. Patterson and M. R. Patterson. **Second Edition, revised.** 92 illustrations. 6x9. Cloth. 334pp. 1896 $4.00

**Solomor, Maurice.** Electric Lamps. 11 illustrations. 6x9 Cloth. 339pp. (Van Nostrand's Westminster Series.) 1908. Net $2.00

**Zeidler, J. and Lustgarten. J.** Electric Arc Lamps: Their Priciples, Construction and Working. 160 illustrations. 6x9. Cloth. 188pp. London, 1908. Net $2.00

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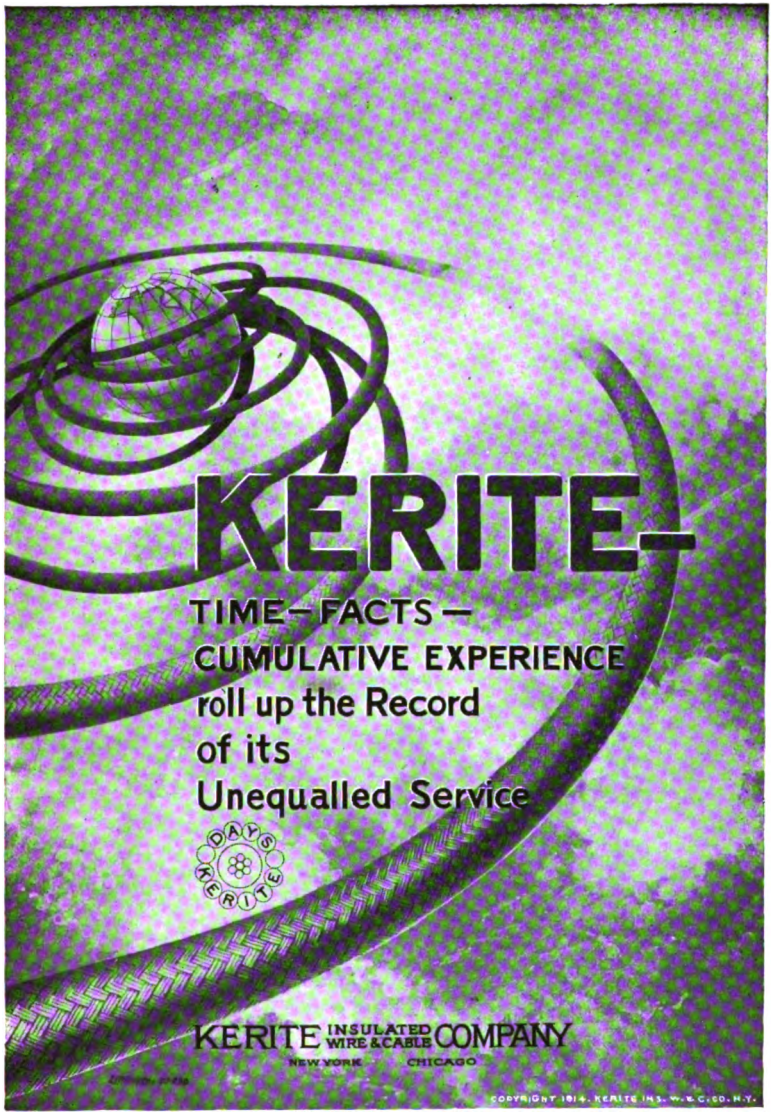


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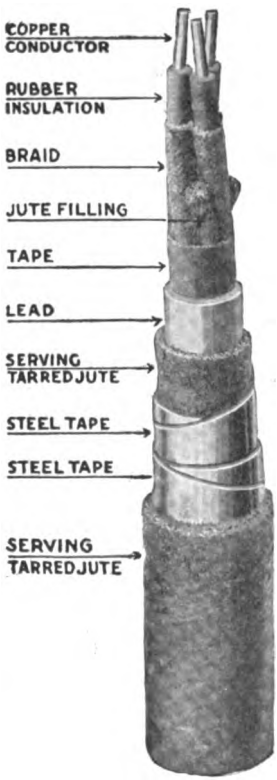


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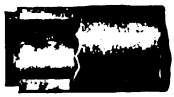

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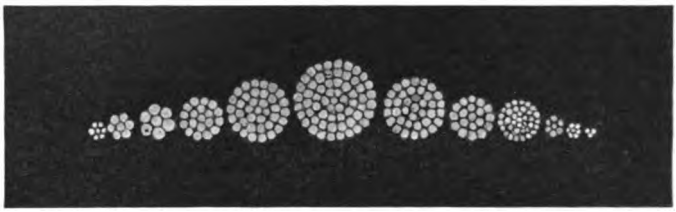

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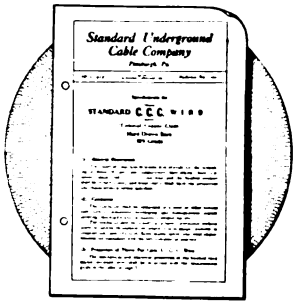


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(Continued from page IX)

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(Continued on page XIII)

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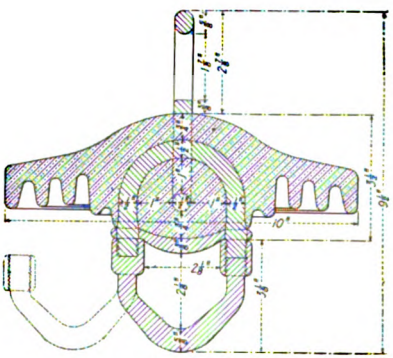

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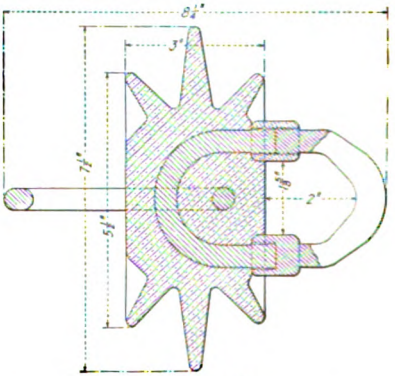

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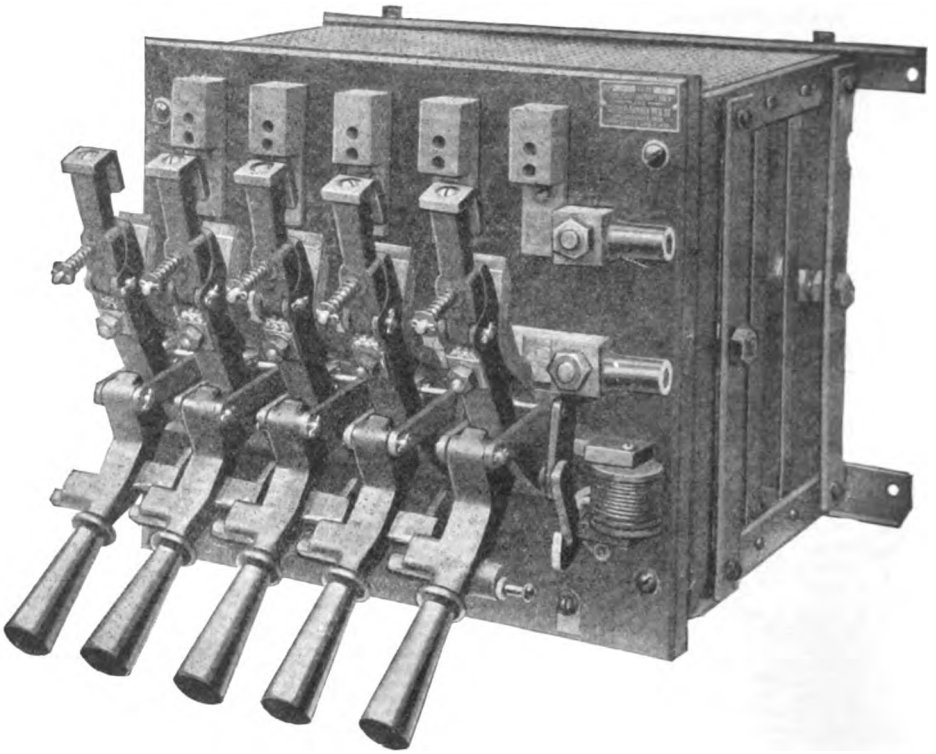

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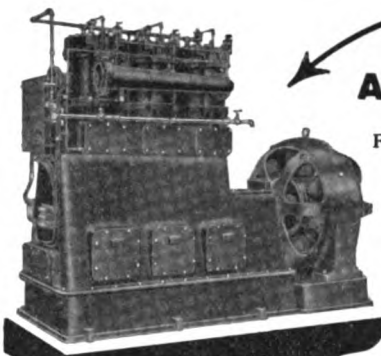

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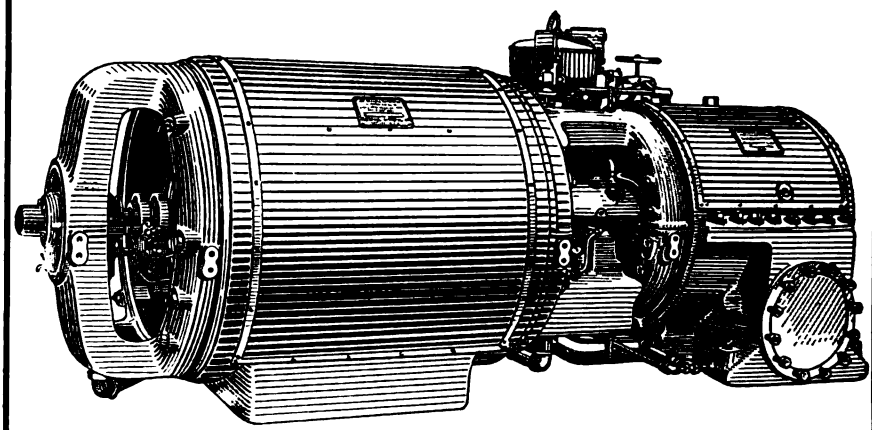

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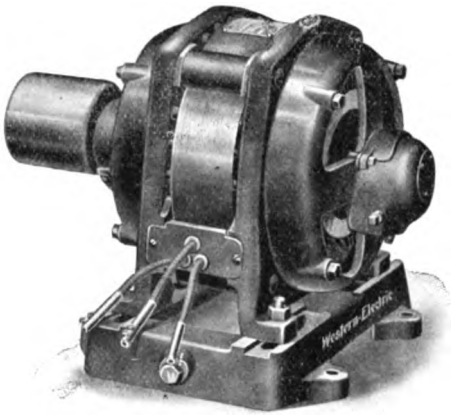


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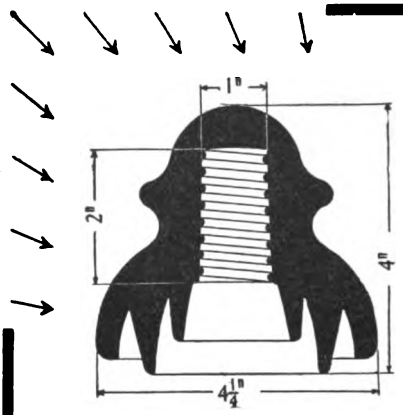


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represents a great electrical improvement and combines characteristics not found in any other polyphase motor

**High Starting Torque**
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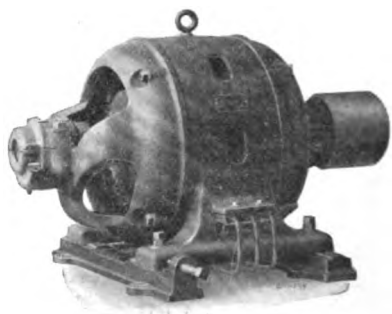

**Absolutely self-starting under heavy loads**

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# *Summary*

## (*Westinghouse Brake Equipment and Facilities*)

**Straight Air Brake** for single cars only, in very light slow-speed city service. Furnished also as a "Featherweight" schedule.

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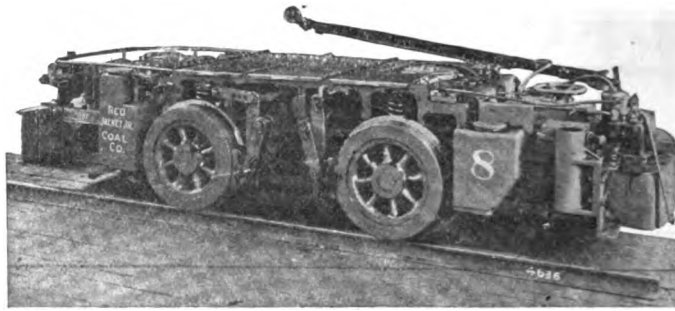


# A Barsteel Gathering Locomotive
## That Will Operate in a 29-inch Clearance

Here is an illustration of a Baldwin-Westinghouse Barsteel electric gathering locomotive that operates successfully in a clearance of twenty-nine inches—36 inches was heretofore considered about the limit for locomotives.

Great care has been exercised in keeping the overall height to a minimum, as is shown in the general construction of the locomotive and the location of the reel.

There is not a projection above the top of the frame anywhere and ample room has been provided to permit the operator to crouch upon his seat.

The reel is driven by an independent motor contained inside the reel drum. This motor is in effect an electrical spring. It tends to wind the cable up and its turning force acts as a brake and keeps the cable taut when the locomotive enters the room and promptly takes up all slack when the locomotive returns.

With this type of reel there is easy access to the locomotive motors, because of its being located out of the way on the rear of the frame. The armature of the reel motor can be readily removed for inspection and overhauling.

Locomotives of this type have successfully solved the problem of gathering in very low rooms. Our specialists in mine haulage, who make a careful study of various mining problems, will be glad to assist you in selecting the proper equipment for your mines.

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Issued monthly by the Institution of Electrical Engineers, London, in association with the Physical Society of London. With the co-operation of the American Physical Society, the American Institute of Electrical Engineers, and the American Electro-Chemical Society.

The contents of the two sections are as follows:

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